August 2015
Project Closeout Report DRAFT
National Spherical Torus Experiment (NSTXU) Upgrade

Project # 000509 MIE-NSTX-U
at
Princeton Plasma Physics Laboratory (PPPL), Princeton, NJ

Office of Fusion Energy Science (FES)
Office of Science
U.S. Department of Energy

Date Approved:

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Month/Year

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PLASMA PHYSICS
LABORATORY

Project Closeout Report for the
National Spherical Torus Experiment (NSTXU) at the
Princeton Plasma Physics Laboratory (PPPL)

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Project Closeout Report for the
National Spherical Torus Experiment (NSTXU) at the
Princeton Plasma Physics Laboratory (PPPL)

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1. EXECUTIVE SUMMARY

The National Spherical Torus Experiment (NSTX) is an experimental research facility funded by Fusion Energy Sciences (FES) that is operating at the Department of Energy's Princeton Plasma Physics Laboratory (PPPL).

The scope of the NSTX Upgrade Project included design, fabrication, installation, and integrated system testing for the systems affected by the project. The Department of Energy has identified the NSTX Upgrade Project as a Major Item of Equipment (MIE) Project instead of a Line Item construction project. The device is located within existing experimental facilities at PPPL. No major building additions were required to accommodate the device.

The technical goals of the project included;
1) Upgrading the NSTX Center Stack (CS). This was accomplished by designing, fabricating, installing and testing a new CS assembly including a new toroidal field (TF) hub assembly, new TF flag assemblies, new ceramic break, new inner TF bundle, new ohmic heating coil, new inconel casing and insulation, new plasma facing component (PFC) tiles, and new poloidal field (PF) 1a, b & c coils. The supporting ancillary systems (power, water, controls) systems were also upgraded.

2) Decontaminating, refurbishing, installing and testing a TFTR neutral beam-line (NBL) on NSTX. This included the evaluation and refurbishment of internal components such as the cryogenic panels, beam dumps, bending magnets, beam scrapers, calorimeter. Additionally, a second set of beam-line services (e.g., power, water, vacuum, cryogenics, etc.) were provided.

All required processes for commissioning have been completed and the project Key Performance Parameters) KPP's) achieved on August 11th 2015.

The project was complete on August 11th, 2015, 1 1/2 months ahead of schedule, at a Total Project Cost (TPC) of $93.7 M, $0.6M under budget.

2. INTRODUCTION

This is the Draft project closeout report for the National Spherical Torus Experiment (NSTX) project which was completed in August 2015. The project is located at Princeton Plasma Physics Laboratory (PPPL) Laboratory, Princeton, NJ

This report documents the scope deliverable, cost and schedule achievements, and lessons learned.

3. ACQUISITION APPROACH

DOE acquired the project through Princeton Plasma Physics Laboratory (PPPL).who had the ultimate responsibility to successfully execute the project.
The technical component design, specifications, fabrication, assembly, installation and test were performed by the Princeton Plasma Physics Laboratory (PPPL) with support provided by Industry for the material and hardware components. Approximately 21% of the total project cost was for outside industry procurements.

The following work/acquisitions were performed as follows:

- Project Management: In-house staff;
- Construction Management: In-house staff;
- Engineering and Design: In-house staff;
- Large Components: Combination of fixed price vendor contracts & in-house fabrication;
- Assembly: In-house staff and fixed price vendor contracts;
- Decontamination: In-house staff;
- Ancillary Systems: Combination of vendor contracts and in-house staff, and;
- System Start-up, Test and Troubleshoot: In-house staff.

Major procurements from industry included;

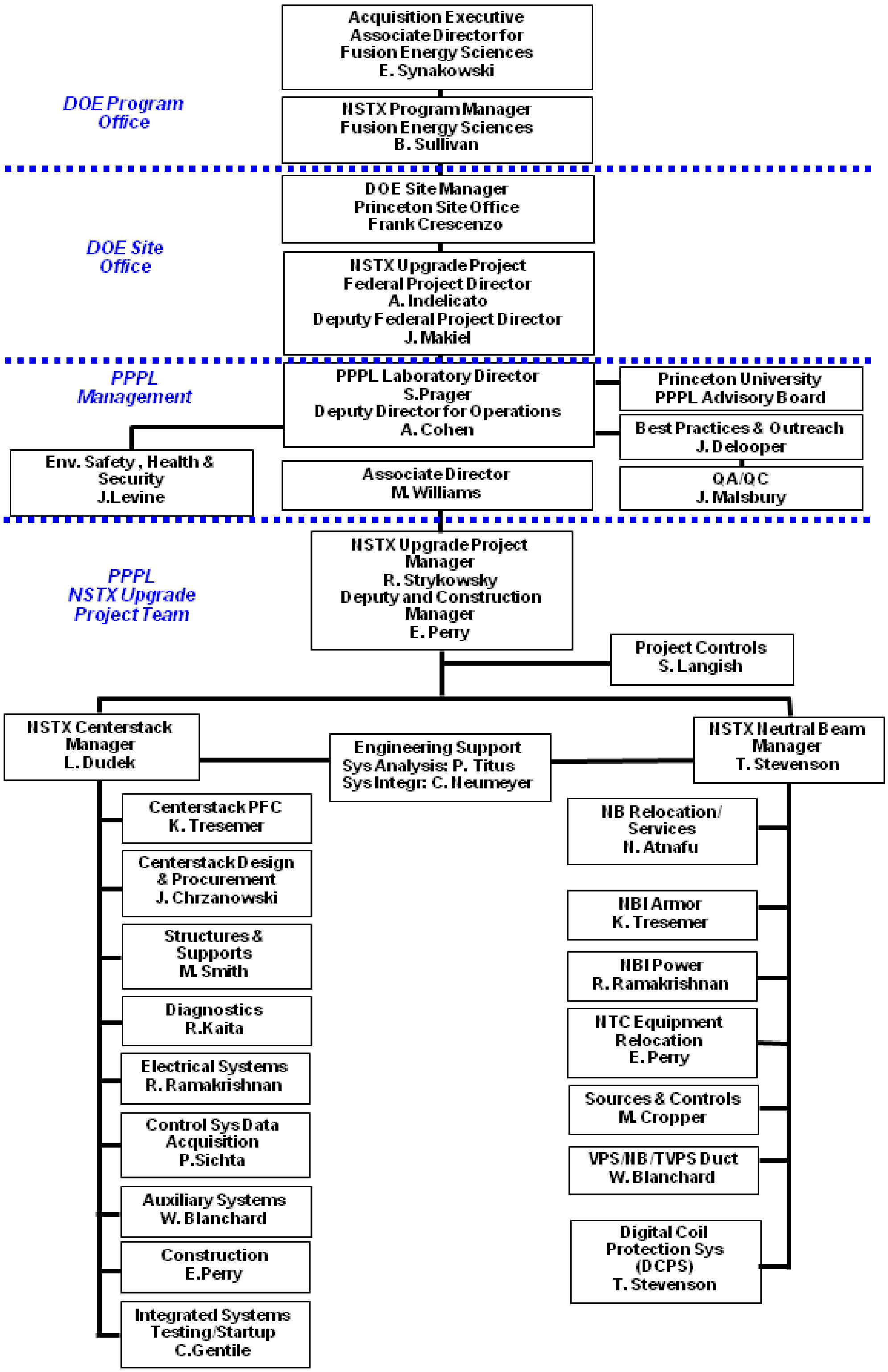
Supplier	**Location**	**Procurement**
Martinez & Turek	Rialto, CA	Centerstack Casing
A&N, Incorporated	Williston, FL	Bay J Port Cover, Bay I Port Cover and various Vacuum Parts
Major Tool and Machine	Indianapolis, IN	Inner TF Conductor Machining
Hollis Line Machine	Hollis, NH	Outer TF Conductor Stiffeners, Organ Pipe Extension Weldment and Ceramic Break Parts
Powers Electric	Columbus, NJ	Wiring and Cabling
Zenex Precision	Paterson NJ	TF Flex Buss
Abcot Amnor	Hawthorne, NJ	Belden/Honeywell Wiring and Cabling
Imperial Machine	Columbia, NJ	G10 Crown Piece and Vacuum Vessel Main Flange Mounting Studs
MWI, Inc.	Rochester, NY	Poco Graphite Tiles
Edison Welding Institute	Columbus, OH	Inner TF Friction Stir Welding
H.C. Starck	Euclid, OH	TZM Molybdenum Inboard Divertor Tiles and Shield Plates
Everson Tesla	Nazareth, PA	PF1 Coils and Outer TF Coil Fabrication
Astro Machine	Ephrata, PA	Copper Lead Spacers, Centerstack Casing Supports, Umbrella Lid and Centerstack Swing Fixture
Carolina Fabricators	West Columbia, SC	Coil Support Structures
Luvata Pori	Kimberly, WI	Inner TF Copper Conductor Extrusions

External technical and management consultation and reviews provided by 72 individual external personnel from the following institutions;

MIT Plasma Science and Fusion Center
US Department of Energy
University of Wisconsin
Argonne National Laboratory
Lawrence Berkeley National Laboratory
Los Alamos National laboratory
Oak Ridge National Laboratory
Fermi
General Atomic
SLAC
National Institute of Standards and Technology
United Kingdom Atomic Energy Authority (UKAEA)

4. PROJECT ORGANIZATION

The project was organized as shown below;



The project team remained relatively intact during course of the project with the exceptions being;

1) The WBS manager for the center stack design, Jim Chrzanowski, retired shortly after the center stack was completed and installed. A senior engineer, Steve Raftopoulos was assigned to carry out the remaining installation and fabrication tasks. There was no impact to the project schedule.
2) In March 2014 a senior electrical engineer, Ronald Hatcher, passed away. Ron was instrumental in designing the Digital Coil Protection System (DCPS). While other PPPL staff closed to fill the ranks there was a schedule impact to the completion of the DCPS system.
3) Mid way through the project the PPPL QA/QC Organization hired a full time dedicated inspector which off-loaded work from the Control Account Managers (CAM's).

5. PROJECT BASELINE

This section documents the project Performance Baseline (PB) that consists of the scope, cost (Total Project Cost or TPC), schedule (Critical Decision or CD-4 date), funding profile, and other information approved at CD-2 and what was achieved at CD-4.

5.1 Scope Baseline

This section describes the project scope and Key Performance Parameters (KPPs) that were approved at CD-2 and the KPPs achieved at CD-4.

The project, located at Princeton Plasma Physics Laboratory (PPPL), designed, constructed, tested, and commissioned the NSTXU device consistent with the scope defined in the project execution plan. :

The major milestone marking the transition from a fabrication project to an operating facility is the first plasma milestone (CD-4). First plasma is defined as;

1) An ohmically heated discharge > 50 kA at a toroidal magnetic field of > 1 kG.
2) The installation of the second neutral beam on NSTX which was considered completed when;
    a. Beamline water, vacuum, cryogenics, and feedstock gas services were attached to the beamline;
    b. Installation of a Torus Isolation Valve and duct interconnecting the NSTX vacuum vessel and the neutral beamline;
    c. Local Control Centers were powered on to monitor power supply status, and;
    d. Project was verified as complete when a 40,000 electron-volt beam was produced and injected into the armor for .050 seconds

The planned and final threshold key performance parameters (KPP) of the project are listed below:

Description of Scope	CD-2 Threshold KPP	KPP Achieved at CD-4	CD-2 Threshold KPP Met or Exceeded?
1. First Plasma *	>50kA plasma at > 1 kG	Completed (8/10/2015)	Exceeded
2a. NBI-Services	Installed/Tested	Installed/Tested	Met
2b. NBI-Connections to Vessel	Installed/Tested	Installed/Tested	Met
2c. NBI-Local controls	Installed/Tested	Installed/Tested	Met
2d. NBI-Beam injection*	≥40kV at 0.05 sec	Completed (5/11/2015)	Exceeded

* Objective evidence for number 1 and 2d shown in Appendix J

5.2 Cost Baseline

At CD-2, approved in December 2010, the ACWP was $14.8M and the EAC (PMB) was $77.3M, leaving a contingency of 27% on the ETC of $62.5M. Table 5.2-1 shows the planned cost, actual cost at CD-4, and explanations of contingency usage. A more detailed look at draw-downs on contingency is documented by PPPL's Engineering Change Proposal (ECP) and is shown in Appendix F.

	WBS	CD-2 Cost Baseline ($M)	Final Cost ($M)	Delta	Explanation (listed in cost order)
	1.1 Torus Systems	$13.5	$26.7	$13.2	1) Under estimated unforeseen tasks and technician time to fabricate and assemble inner TF and OH coil 2) Over sight and supervision due to schedule stretch-out plus provide additional to support CAM. 3) Vendor hardware fabrication cost 4) Assembly hardware fabrication (i.e. winding station, inner TF cooling tube soldering station) 5) Scope enhancements: >PF-1c Protective measures (464k), > Passive plate redesign, fabrication & re-inforcement $732k,
	1.2 Plasma Heating	$21.0	$17.6	$3.3	1) Over-estimated beamline relocation, NBI power , NBI controls 2) Under estimated NBI Armor, NBI VPS/Interface duct 3) Reduced scope for non key diagnostic re-installations 4) Scope enhancements: S-FLIP port installation $165k
	1.3 Auxiliary Systems	$0.4	$0.7	$0.3	1) Under estimated labor and unforeseen tasks 2)Under estimated vendor hardware fabrication cost
TEC	1.4 Plasma Diagnostics	$1.6	$2.3	$0.8	1) Under estimated unforeseen tasks MPTS, tFIDA and RWM coil 2) Scope enhancements: RWM coil, and diagnostic accommodations. $356
	1.5 power Systems	$7.9	$10.1	$2.2	1) Underestimated the design, implementation and testing of DCPS 2) Underestimated power systems bus bar fabrication 3) Power systems came in under budget 4) Scope enhancements: Redundant DCPS computer, Halmar Signal Conditioner interface box, Temp. conn. panel, RTC interface chassis $286k
	1.6 Central I&C	$0.9	$1.1	$0.2	1) Underestimate engineering and implementation tasks 2) Scope enhancements: Genuine real-time control computer, new higher-performance input/output boards, and a complete restructuring of the software architecture to achieve better reliability, improved performance, lower maintenance $260k
	1.7 Project Support & Integration	$11.0	$11.3	$0.4	1) Project stretch-out increase for project office but somewhat offset by over estimates of HP and CS/NB management
	1.8 Assembly	$7.6	$10.3	$2.7	1)Under estimated & unforeseen tasks and technician time 2) Repairs due to Arc fault ($361K)
	TEC Subtotal	**$63.8**	**$80.2**	**$16.4**	
	1.1 Torus Systems	$4.8	$4.8	-	
	1.2 Plasma Heating	$3.6	$3.6	-	
	1.3 Auxiliary Systems	$0.0	$0.0	-	
OPC	1.4 Plasma Diagnostics	$0.2	$0.2	-	
	1.5 power Systems	$1.4	$1.4	-	
	1.6 Central I&C	$0.0	$0.0	-	
	1.7 Project Support & Integratic	$3.4	$3.4	-	
	1.8 Assembly	$0.0	$0.0	-	
	OPC Subtotal	**$13.5**	**$13.5**	-	
	Subtotal (TEC + OPC)	**$77.3**	**$93.6**	**$16.4**	
	Total Contingency	**$17.0**	**$0.6**	**$16.4**	
	Total Project Cost	**$94.3**	**$94.3**	**$0.0**	

Table 5.2-1 Comparison of the project baseline to completed cost including contingency utilization

WBS and CA	CD-2 Cost Baseline ($M)	Final Expected Cost ($M)	Delta
1.1 Torus Systems	$18.3	$31.5	-$13.2
1000 CSU Analytical Support	$0.4	$0.7	-$0.3
1001 CS Plasma Facing Components	$2.2	$1.9	$0.2
1002 Passive Plate Analysis & Upgrade	$0.3	$0.7	-$0.4
1200 Structures & Supports	$3.5	$4.5	-$1.0
1300 Center Stack	$1.1	$3.5	-$2.4
1301 Outer TF Coils	$0.3	$0.5	-$0.1
1302 Center Stack Assembly	$1.0	$1.0	$0.0
1303 TF Joint Test Stand & Test	$0.4	$0.2	$0.1
1304 Inner TF Bundle	$2.6	$4.1	-$1.6
1305 Ohmic Heating Coil	$4.6	$11.1	-$6.6
1306 Inner PF Coils	$0.7	$1.1	-$0.4
1307 CS Casing Assembly (Chrzanowski)	$0.9	$1.7	-$0.8
1310 CSU Magnets Systems	$0.4	$0.4	$0.0
1.2 Plasma Heating	$24.6	$21.3	$3.3
2300 ECH Analysis	$0.1	$0.0	$0.1
2420 2nd NBI Sources	$1.1	$0.1	$1.0
2425 BL Relocation	$1.9	$1.3	$0.6
2430 2nd NBI Decontamination	$2.1	$2.1	$0.0
2440 2nd NBI Beamline	$2.6	$1.6	$1.0
2450 2nd NBI Services (Cropper)	$4.5	$4.4	$0.2
2460 2nd NBI Armor	$0.7	$1.0	-$0.3
2470 2nd NBI Power (Raki)	$3.3	$3.0	$0.3
2475 2nd NBI Controls (Cropper)	$2.1	$1.9	$0.2
2480 2nd NBI/TVPS Duct	$2.3	$2.5	-$0.2
2485 Vacuum Pumping System	$0.4	$0.4	-$0.1
2490 NTC Equipment Relocations (Perry)	$3.6	$3.0	$0.6
1.3 Auxiliary System	$0.4	$0.7	-$0.3
3200 Water Cooling System Mods (Atnafu)	$0.2	$0.5	-$0.3
3300 Bakeout System Mods CSU (Raki)	$0.1	$0.2	-$0.1
3400 Gas Delivery System Mods (Blanchard)	$0.1	$0.1	$0.0
1.4 Plasma Diagnostics	$1.8	$2.5	-$0.8
4100 Center Stack Diagnostics	$0.8	$0.8	$0.0
4500 MPTS VV Modification	$0.9	$1.6	-$0.7
4501 Bay A and L RWM Coil (Labik)	$0.0	$0.1	-$0.1
1.5 Power Systems	$9.4	$11.5	-$2.2
5000 CSU Power Systems (Raki)	$5.7	$4.7	$1.1
5200 DCPS (Stevenson)	$2.5	$4.1	-$1.6
5501 Coil Bus Runs (Atnafu)	$1.1	$2.7	-$1.6
1.6 Central I&C	$0.9	$1.1	-$0.2
6100 Control Sys Data Acquisition (Sichta)	$0.9	$1.1	-$0.2
1.7 Project Support & Integration	$14.4	$14.7	-$0.4
7100 Project Management & Integration (Strykowsky)	$5.8	$7.1	-$1.3
7200 Center Stack Management (Dudek)	$1.5	$1.4	$0.2
7300 NB2 Management (Stevenson)	$1.5	$0.9	$0.5
7400 Health Physics Support (Stevenson)	$2.5	$2.5	$0.0
7710 NSTX-U HP and Other Allocations (Strykowsky)	$3.0	$2.8	$0.2
7900 Integrated System (Gentile)	$0.1	$0.0	$0.0
1.8 Assembly	$7.6	$10.3	-$2.7
8200 CS & Coil Supt Struct Install (Perry)	$6.5	$6.7	-$0.3
8210 Field Supervision & Oversight (Perry)	$0.0	$1.4	-$1.4
8250 Remove/Install Centerstack (Perry)	$1.2	$1.7	-$0.6
8251 OH Arc Fault recovery	$0.0	$0.4	-$0.4
PMB	$77.3	$93.6	-$16.4
Subtotal (TEC + OPC)	$77.3	$93.6	-$16.4
Total Contingency (TEC + OPC)	$17.0	$0.6	$16.4
Total Project Cost	$94.3	$94.3	$0.0

Table 5.2-2 Comparison of the project baseline to completed at the cost account level

PROJECT ID	***MIE-NSTX-U***		
PROJECT NAME	***NSTX Upgrade***		
PROJECT LOCATION	***PPPL***		
TOTAL PROJECT COST ($K)	***$94,300***		
DESCRIPTION OF PROJECT AND UNIQUE FEATURES	***The scope of the NSTX Upgrade Project includes design, fabrication, installation, and integrated system testing of both a new and more robust center coil and the addition of a second neitral beam heating system.***		
DATE OF COST ESTIMATE	**January-2012**		
Cost Categories	**Project $(K)**	**Non-Project $(K)**	**Comments**
Engineering	**$18,659**		
Design (A/E, tech specs.; conceptual, preliminary, and final design; as-built drawings, etc.)	Yes	No	Conceptual, preliminary and final design. Cost estimated based on resource loaded schedule with 10% estimated contingency draw down added.
Value Engineering	Yes	No	
Design Reviews	Yes	No	CDR, PDR, FDR, Peer reviews
Design Support (i.e., soil testing, vibration testing, seismic analysis, etc., needed for design)	Yes	No	
Other (specify)	Yes	No	Includes Title III engineering, necessary R&D development and prototyping
Management	**$12,184**		
Design Management	Yes	No	Cost based on ACWP and ETC for Cost Accounts 7100, 7200,7300,7710
Construction Management	Yes	No	
Project Management (cost estimating, scheduling, project controls, risk assessment, etc.)	Yes	No	Includes cost for non-project initiated reviews
QA,Inspection/testing/acceptance/etc.	No	No	QA, Accounting, Procurement, Safety, ES&H, Environmental are indirect cost included in all cost elements as part of PPPL overhead.
Procurement and Contracting	No	No	
Legal, Accounting, Real Estate	No	No	
Other (specify)	No	No	
ES&H	**$0**		QA, Accounting, Procurement, Safety, ES&H, Environmental are indirect cost included in all cost elements as part of PPPL overhead.
Environmental Permitting	No	No	
Safety documentation	No	No	
Safety Inspection	No	No	
Security	No	No	
Other (specify)	No	No	
Construction/Fabrication	**$62,804**		Includes Decontamination, Fabrication / Assembly, Installation, Procurement, Refurbishment, and Testing. Includes cost accounts 7900 startup
Building & Land	No	No	
Special Equipment (i.e., microscopes, probes, instruments, detectors, etc.)	Yes	No	
Standard Equipment (i.e., furniture, office equipment, benches, kitchen equipment, audio/visual, etc)	Yes	No	
Demolition/Disposal	No	No	
Research and Development (R&D)	No	No	R&D included under engineering
Commissioning and Testing	Yes	No	
Other (specify)	No	No	
Contingency Remaining	**$653**		
Total	**$94,300**	**$0**	
	CD Planned	**Actual Dates**	**Comments**
Critical Decision-1	April 2010 (A)		
Critical Decision-2	January 2011	December 2010 (A)	
Critical Decision-3	January 2012	December 2011 (A)	
Critical Decision-4	September-15	August 2015(A)*	*** Scope & KPP's accomplished. ESSAB approval still pending**

Table 5.2-3 EDIA Cost Compared to Construction. Note due to the difficulty in segregating these cost within each control account the engineering cost was estimated based on the baseline resource loaded schedule plus a factor for contingency application.

5.2.1 Contingency

The amount of contingency established at the beginning of the project was based on a risk assessment performed as part of the cost estimating process. Total cost contingency included 3 elements: 1) a task-by-task subjective contingency assessment for unknowns and uncertainties; 2) a weighted assessment of tabulated risk events, and; 3) schedule contingency applied to accommodate potential project stretch-out (a.k.a. "standing army"cost). Schedule contingency (in months) was calculated by applying the task-by-task contingencies to the task durations to calculate the longest path within the project. This was offset partially by the option of using second shift and overtime to maintain schedule. The initial project contingency level was approved by the Associate Director for Fusion Energy Sciences as the Acquisition Executive for NSTX Upgrade Project at CD-2 as part of establishing the overall cost and schedule baseline. The basis for the risk events were based on the project risk registry shown in Appendix E.

End of Fiscal Year	% Project Complete	TPC ($K)	ACWP ($K)	Contingency remaining ($K)	ETC ($K)
FY 2010	18%	$94,300	$13,816	$17,000	$63,484
FY 2011	27%	$94,300	$21,589	$15,330	$57,381
FY 2012	52%	$94,300	$43,081	$11,894	$39,325
FY 2013	72%	$94,300	$63,402	$6,673	$24,225
FY 2014	94%	$94,300	$86,898	$1,842	$5,560
31-July-2015	100.0%	$94,300	$93,546	$753	$101

Figure 5.2-4 Summary Contingency history as function of project percent complete. Contingency drawdown defined as documented ECP's and cost Variances (or simply TPC-EAC).

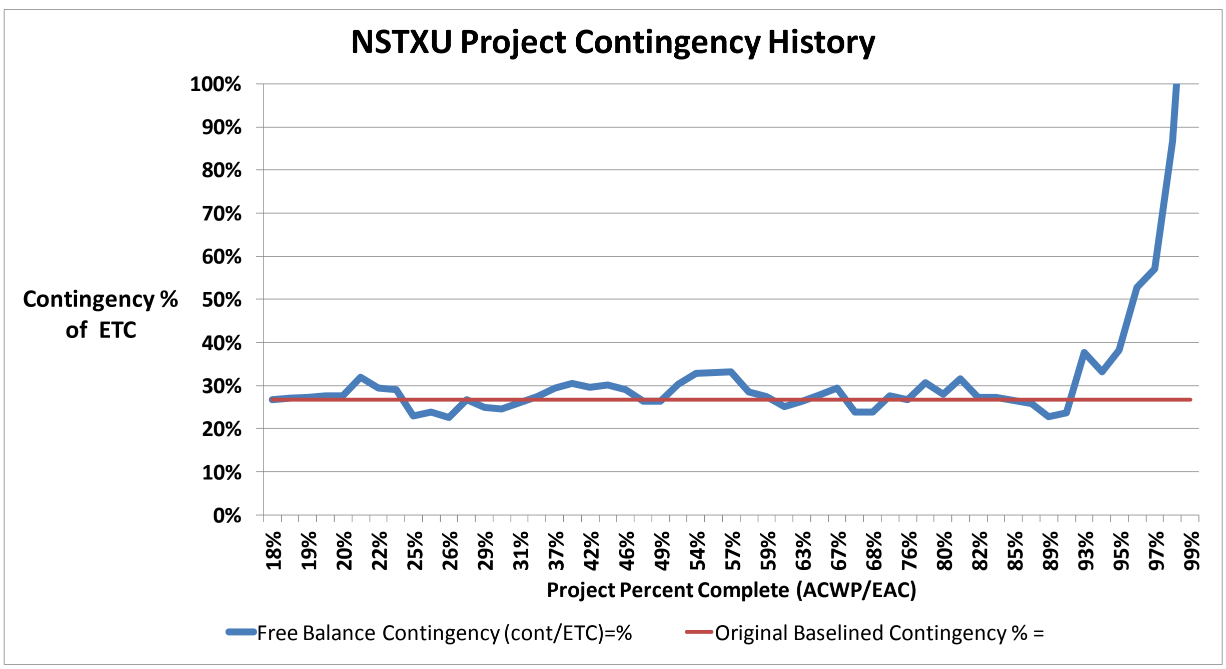


Figure 5.2-5 Contingency usage trend plot as function of project percent complete.

5.3 Schedule Baseline

The NSTXU Project was completed in August 2015 approx 1 1/2 months ahead of schedule. Table 5.3-1 shows the project milestones per the Project Execution Plan (PEP).

Level	Milestone	Schedule at CD-2 (per PEP)	Actual	Months ahead/ (behind)	
Level I	**Receive CD-0 Approval**	-	**Feb-09**		
Level I	**Receive CD-1 Approval**	-	**Apr-10**		
Level II	Project Preliminary Design Review	-	Jun-10		
Level II	Neutral Beam #2 Decontamination Program Complete	-	Nov-10		
Level I	**Receive CD-2 Approval**	**Jan-11**	**Dec-10**	**1.3**	
Level II	Project Final Design Review	Sep-11	Jun-11	3.3	
Level I	**Receive CD-3 Approval**	**Jan-12**	**Dec-11**	**1.4**	
Level II	Friction Stir weld Coil Leads TF Conductors	Jun-12	(3)		
Level II	NSTX Complete Operations	Jul-12	Sep-11	10.9	
Level II	Begin Upgrade Outage	Aug-12	Sep-11	11.6	(1)
Level II	Begin Inner TF Quadrant Fab (Apply Turn Insul #1 Quad)	Apr-13	Jun-12	10.5	
Level II	Award Neutral Beam (NB) Vessel Cap	Jun-13	Feb-11	28.5	
Level II	Complete Assy and Pot Of 4th Inner TF Quadrant	Oct-13	Jun-13	4.8	
Level II	Complete Fabricate & Test Inner TF/OH Coil Assy	Jul-14	Jul-14	0.3	(2)
Level II	NB Cap Installed	Oct-14	Jan-13	21.9	
Level II	Lift In New Centerstack	Jan-15	Oct-14	3.7	
Level II	Complete ISTP	Aug-15	Aug-15	0.5	
Level II	Resume Operations	Sep-15	Aug-15	1.5	(4)
Level I	**CD-4**	**Sep-15**			

Table 5.3-1 Project Milestones

It should be noted that the project began the upgrade outage ((1) level II milestone) on September 2011 11.6 months ahead of schedule AND ahead of CD-3. This acceleration was a result of NSTX operations being curtailed due to an inner TF coil failure. The start of the outage ahead of CD-3 was approved by DOE (ECP-004) and consisted of hardware removal tasks only.

(2) The level II milestone "Complete Fabricate & Test Inner TF/OH Coil Assy" occurred on July 2014. Its original baseline date was June 2014 but its slippage was anticipated therefore the milestone date was rescheduled by one month as documented in ECP-114.

(3) The level II milestone "Friction stir weld Coil Leads TF Conductors" had been planned to be a stand-alone subcontract. The scope for this work was actually added to the overall Inner TF machining subcontract which was award to Major-Tool and Machine in August 2011.

(4) Initial ISTP completed in April 2015 however during an attempt at a 100% power shot, just prior to a first plasma attempt , an OH coil arc fault occurred which resulted in an extensive internal and external investigation process as well as hardware repairs. Subsequent to hardware repairs being made and reconciliation of a root cause analysis findings the PPPL executive ES&H committee approved ISTP testing to resume. The successful ISTP testing led to a first plasma being achieved on August 10, 2015. Results of the arc fault corrective action plan can be found in appendix O.

Figure 5.3-2 is a high level summary schedule showing Level I milestones, and tasks. The large bars represent the baseline schedule at CD-2 and the narrow lines show actual completion dates. The critical path is shown as pink/red and the non-critical path shown as blue. As had been predicted the critical path was the fabrication and assembly of the center stack magnet assembly. The schedule stretch-out was the result of vendor challenges in machining the inner TF conductors as well as the additional time for PPPL technicians to assemble and test the magnets. Fortunately, the highest risks, TF & OH coil VPI operation, were successfully averted.

Prior to the start of the ISTP a readiness to operate review was conducted by an external committee to ensure that the commissioning and subsequent operation of the National Spherical Torus experiment Upgrade (NSTX-U) could be performed in a safe and environmentally responsible manner. (See Appendix M). Recommendations from the review were implemented which led to a safety certificate for operation granted by the PPPL ES&H executive committee on April 10, 2015 (see Appendix N).

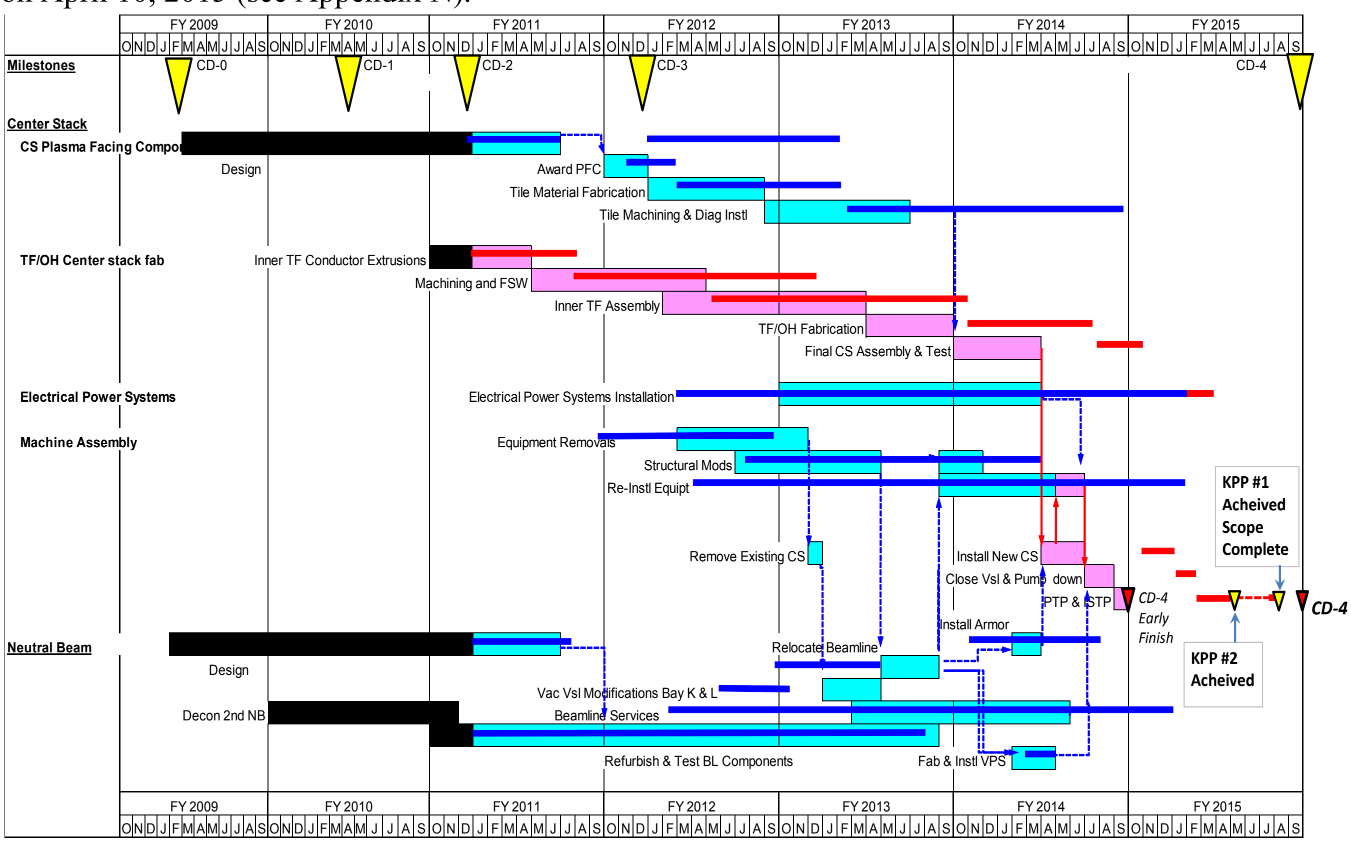


Figure 5.3-2 Summary Schedule

5.4 Work Breakdown Structure

The following is the Level II Work Breakdown Structure (WBS) for the NSTXU project developed for the original construction of NSTX in 1999. The NSTXU Upgrade required changes to a subset of this scope. The detailed NSTXU WBS dictionary (Level II) is shown in Appendix A with the WBS elements that required changes highlight in yellow (along with their Control Account (CA)).

NSTXU Level II WBS	
Title	**Description**
1.1 Torus Systems	The torus systems include all the systems and related elements within the boundary of the NSTX support structure. This WBS element includes the Plasma Facing Components (WBS 1.1), Vacuum Vessel & Support Structure (WBS 1.2), and Magnet Systems (WBS 1.3). The scope of the work contains engineering design, R&D, mockups, procurement activities, and component fabrication. Assembly of the Torus System is included in WBS 1.8.
1.2 Plasma Heating and Current Drive Systems	The heating and current drive systems include all the auxiliary plasma heating and current drive systems. This WBS element includes the High Harmonic Fast Wave (HHFW) Current Drive System, the Coaxial Helicity Injection (CHI) Current Drive System, the Electron Cyclotron Heating (ECH) System, and the Neutral Beam Injection (NBI) System. Only ECH (WBS 1.2.3) and Neutral Beam Injection (WBS 1.2.4) are impacted by the NSTX Upgrade Project. The scope of the work contains engineering design, R&D, mockups, procurement activities, component fabrication, installation, and System Testing. Installation of the WBS 2 systems is included in the individual WBS 2, level 3 elements.
1.3 Auxiliary Systems	This WBS element includes the Coolant Systems, the Bakeout Heating System, Gas Delivery System and the Glow Discharge Cleaning System. The scope of the work contains engineering design, procurement activities, component fabrication, and System Testing. Installation of the WBS 3 systems is included in the individual WBS 3, level 3 elements.
1.4 Plasma Diagnostics	The Plasma Diagnostics provide information on discharge parameters to characterize NSTX plasmas and guide its operation for optimized performance. The near term emphasis will be on detailed measurements of plasma profiles, using equipment presently available at PPPL. The long term objective will be to provide input for advanced plasma control systems, using new concepts and systems developed by the national NSTX team.
1.5 Power Systems	The Power Systems WBS element includes the engineering, design, prototyping, procurement and installation of all the systems and related elements that provide conditioned electrical power and energy to the NSTX systems. It includes the AC Power Systems, the AC/DC Convertors, the DC Systems, the Control and Protection System, and System Design and Integration as well as the coil bus runs..
1.6 Central Instrumentation and Controls (I&C)	This upgrade will be capable of producing plasmas on the order of 6.5 seconds; to-date they are less than two seconds. For dozens of CAMAC and PC-based data acquisition systems this will require an upgrade, and, in some cases, replacement. The real-time plasma control system will require an upgrade to accommodate additional input/output signals, control loops, and a longer control period. The networks and analysis pool computers will need to be upgraded to achieve reasonable performance for time-sensitive functions. Some test cell racks will be relocated; there will be a modest effort required to route the control, timing, and communication cabling and qualify the systems.
1.7 Project Support & Integration	Project support and integration includes the non-hardware related subsystems such as overall Project Management and Administration, Project Physics as well as Integrated Systems Testing support.
1.8 Site Preparation and Assembly	Site preparation and torus assembly includes modifications to the existing NSTX Test Cell components and subsystems and the assembly and installation of all Torus Systems (WBS 1.1). Modifications to other PPPL facilities, components, and subsystems outside the NSTX Test Cell and the assembly and installation of non-torus components and subsystems are included in the individual components and subsystems.

5.5 Funding Profile

Tables 5.5-1 through 5.5-3 represent the Baseline funding profile, actual funds received and actual cost. DOE had provided accelerated funding starting in FY 2011 primarily to support the acceleration of the machine outage. The machine outage acceleration was a result of the FY 2012 run period being curtailed due to a failure of the existing inner TF conductor which was deemed to be unrepairable.

Table 5.5-1 Funding Profile Approved at CD-2 ($M)

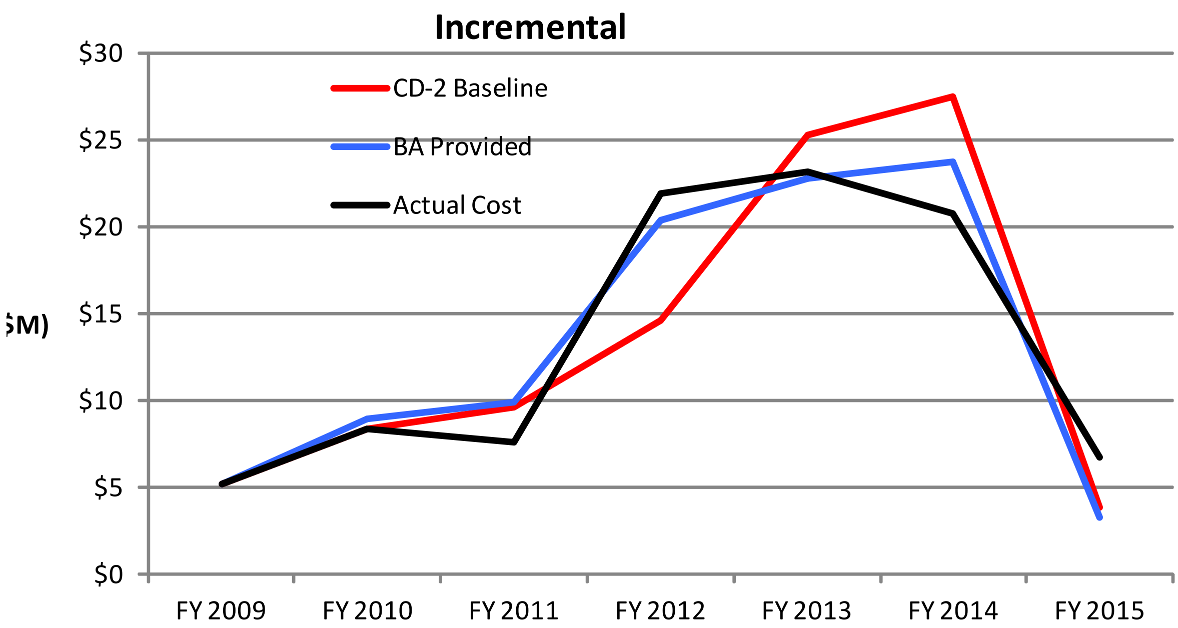
	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total ($M)
OPC	$5.1	$5.6						$10.8
TEC		$2.7	$9.6	$14.6	$25.3	$27.5	$3.8	$83.5
TOTAL	**$5.1**	**$8.3**	**$9.6**	**$14.6**	**$25.3**	**$27.5**	**$3.8**	**$94.3**

Table 5.5-2 Actual Funds Received ($M)

	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total ($M)
OPC	$5.2	$5.4	$0.1					$10.8
TEC		$3.6	$9.8	$20.4	$22.8	$23.7	$3.3	$83.5
TOTAL	**$5.2**	**$8.95**	**$9.9**	**$20.4**	**$22.8**	**$23.7**	**$3.3**	**$94.3**

Table 5.5-2 Actual Cost ($M)

	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	Total ($M)
OPC	$5.1	$5.6	$0.0					$10.8
TEC		$2.7	$7.6	$21.9	$23.2	$20.7	$6.7	$82.9
TOTAL	**$5.1**	**$8.32**	**$7.6**	**$21.9**	**$23.2**	**$20.7**	**$6.7**	**$93.6**



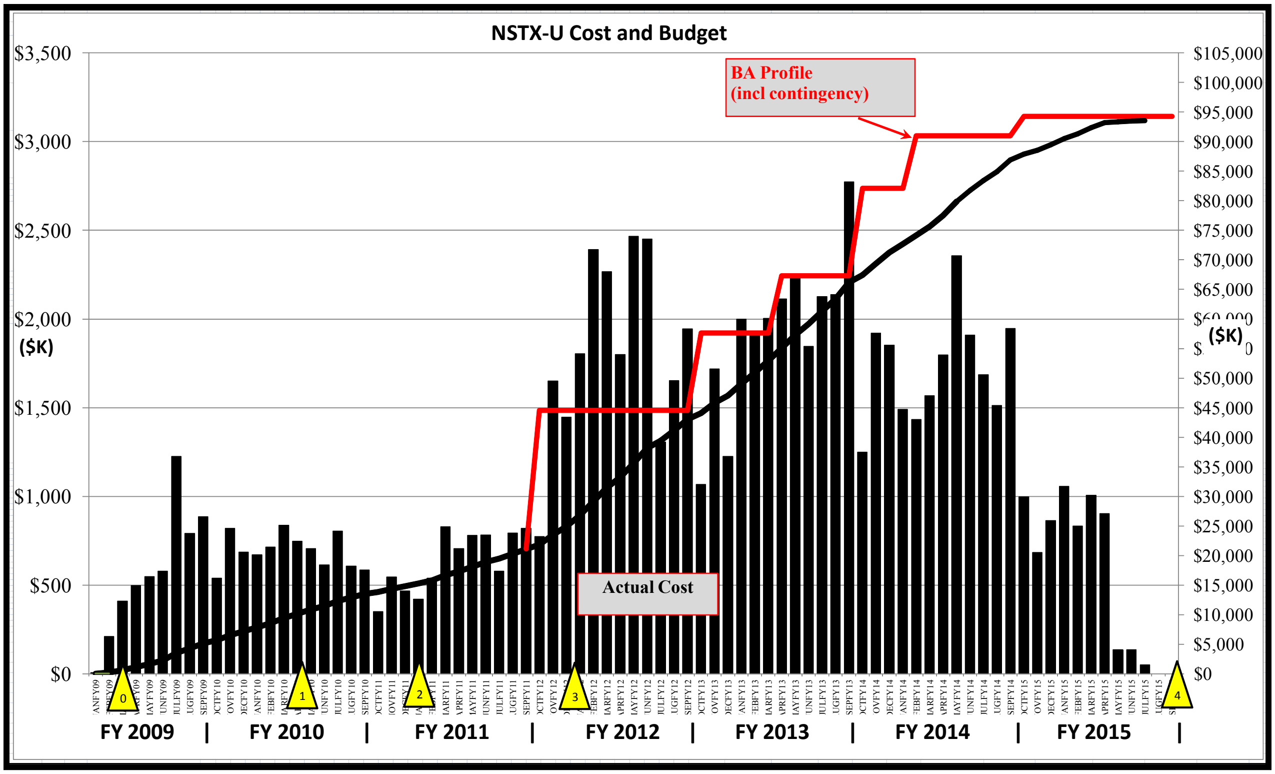


Table 5.5-4 Shows project actual cost detail as compared to the Available project BA.

5.6 Staffing Profile

Figure 5.6-1below shows the actual project FTE profile by fiscal year.
Subcontractors and hourly consists of engineers, designers, and technicians as required to supplement PPPL staff. Excluded are fixed price subcontracts for Davis –Bacon work. Scientist/Researchers provided consultation during the project and were paid by NTSXU Operations. Important contributions were provided by PPPL Procurement, QA/QC, Safety, ESU, and the Engineering front Office whose cost was not directly charged to the project but recovered as part of the PPPL overhead.

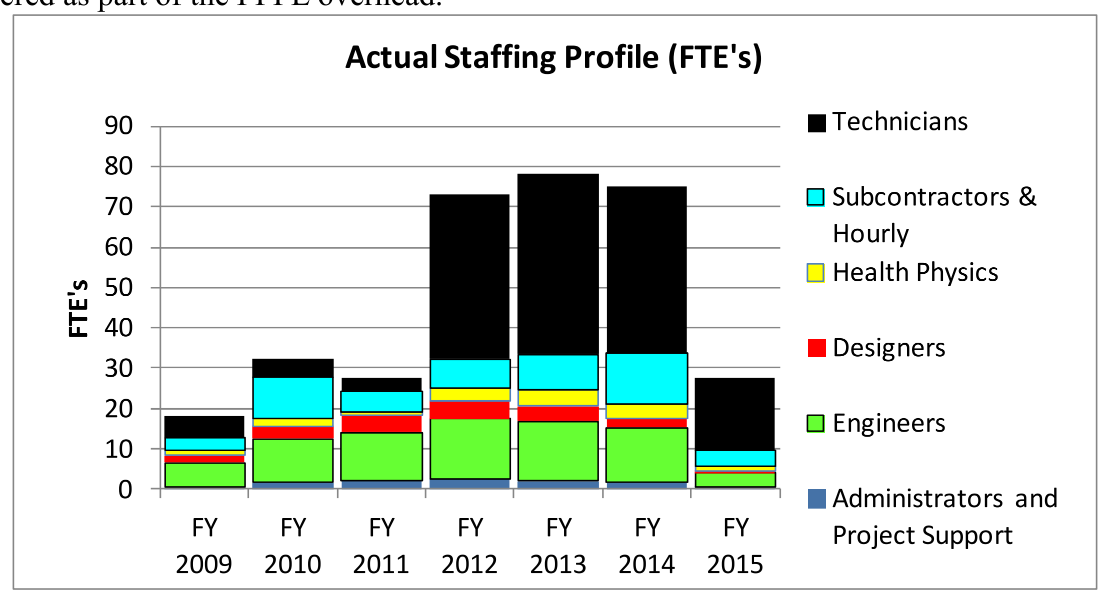


Figure 5.6-Actual project FTE profile by fiscal year.

5.7 Environmental Requirements/Permits

A NEPA determination as a Categorical Exclusion under 10CFR1021, Category B3.13 (Magnetic fusion experiments, no tritium fuel use") was made by the DOE-PSO NEPA Compliance Officer in March 2009."

Upgrades to the NSTX experiment had been addressed in the NSTX Environmental Assessment (DOE/EA-1108; FONSI issued 12/8/95), including plasma currents up to 2 MA and pulse lengths up to 60 sec.

5.8 Safety Record

Table 5.8-1 summarizes the yearly project safety record by organization and type. See Appendix D for the specific injury data.

Table 5.8-1—Summary of Project Safety Record

	Fiscal Year	Hours Worked	Recordable Cases	Recordable Rate	Recordable TARGET DOE (General Industry)	DART cases	DART Rate	DART TARGET DOE (General Industry)
PPPL	FY 2009	31,158	1	6.42		1	6.42	
	FY 2010	56,154	0	0.00		0	0.00	
	FY 2011	47,802	0	0.00		0	0.00	
	FY 2012	126,200	0	0.00		0	0.00	
	FY 2013	134,855	1	1.48		0	0.00	
	FY 2014	129,876	2	3.08		1	1.54	
	FY 2015 (1)	47,560	1	4.21		1	4.21	
	Total Lab	**573,605**	**5**	**1.74**	**3.8 (2)**	**3**	**1.05**	**2.2 (3)**
Contractors	FY 2009							
	FY 2010							
	FY 2011							
	FY 2012		NONE					
	FY 2013							
	FY 2014							
	FY 2015							

(1)Through 7/31/2015

(2) The "Recordable TARGET DOE (General Industry)" (see http://www.bls.gov/news.release/osh.t01.htm for 2013, Construction).

(3) The "DART TARGET DOE (General Industry)" (see http://www.bls.gov/news.release/osh.t01.htm for 2013, Construction).

6. CLOSEOUT STATUS

As of July 31th, 2015, the following is the status of closeout activities.

Activity and Description	Complete—Yes or No?	Planned Completion Date?	Planned Remaining Costs ($K)?
Completion of punch list items	Yes		
Closeout all cost control accounts except CA7100 for project management	Yes		
Administrative & Manmagement Closeout—Cost associated with contract and financial closeout activities.	No	9/30/2015	$75K
Financial Closeout—will be closed after fiscal year close (rates)	No	9/30/2015	+/- $25K
Disposition and close open encumbrances (procurements & s/c)	No	9/30/2015	~~$10K

7. LESSONS LEARNED

The project compiled and ranked lessons lessons-learned (LL) into 3 levels. Rank 1 had the most profound effect on the success of the project or which caused the largest cost, schedule and technical impact. Level 1 LL are discussed here in this section while the complete listing of LL are shown in Appendix H. These rankings are the subjective opinion of the project manager Listed below are the top 4 opportunities and top 3 successes.

<u>Top 4 opportunities:</u>
From the folder of "what would we do different next time" there are 4 major events that stand out.

1. <u>Aqua pour affair.</u> A water-soluble casting material, "Aquapour", was used to maintain a thermal expansion gap between the center stack TF and OH winding. This process proved beneficial in winding the CS OH conductor, however, we were not able to remove the aqua pour as planned due to it being impregnated with epoxy. This setback resulted in a critical path schedule delay and will impose additional operational considerations. Even though this event was postulated in the risk registry, we could have excised additional engineering due diligence to better understand the failure mechanisms that could result in the aqua pour being non removable. For example; while we did perform two R&D simulations we did not subject the process to the epoxy impregnation step. This would have flushed out a failure mode of epoxy migrating into the aqua pour area due to thermal expansion of the conductor and mold. A better sealing scheme perhaps could have been envisioned or this may have resulted in the abandonment of the aqua pour technique in favor of using a different boundary material. We need to better think through technical,

fabrication and assembly risk and determine engineered mitigation plans. At the very least we could have had a better understanding of the cost and schedule impacts. It must also be pointed out that our project's design underwent multiple external reviews with many outside labs participating so this is should not be looked at as a failure but an opportunity to take stock and learn. PPPL has very talented and experienced people having performed similar operations and fabrication tasks successfully in the past. This is good and the reason our projects are technically successful. However, experience and familiarity could easily turn into an air of overconfidence or "trust us we've done it before" mindset. We need to maintain a healthy dose of skepticism in evaluating our work. For example while we do have good design reviews perhaps we need to incorporate a failure modes and effects analysis. It's the underlying human mindset we must recognize and change.
Results of an independent peer review on the operational impacts of the Aquapour can be found in appendix L

2. <u>Better balance in assigning CAM's to scope.</u> The centerstack design and fabrication was assigned to one CAM who was the laboratory's expert in coil manufacturing. The work scope should have been distributed to at least 3 CAM's. The failure to do so led to some oversights in procurement inspections, timely reconciliation of cooling wave analysis, more complete field supervision, and support of EVMS CAM duties. The Center stack WBS relied heavily on one senior CAM who quickly became overloaded. This led to a bottleneck in fabrication tooling which required a lot of attention. Some earlier support on engineering the tooling might have helped save rework. Additionally, an overloaded CAM impacted our schedule since we tended to focus on the near critical path and big ticket procurements or those that are technically challenging. While this helped us to successfully navigate the 6 largest risks on the project (i.e. Vacuum Pressure Impregnation (VPI) of the centerstack) this led to smaller procurements of hardware to receive less attention until it came time for assembly. Some of these components had to be re-worked by PPPL to meet specification which led to internal schedule delays and diversion of critical staff (i.e. welders, machinists).
   - Next time: Ensure CAM's are not overloaded and adequate staffs are assigned for oversight and supervision. Ensure PPPL QC has adequate resources to support the receipt inspection process.

3. <u>Procurement:</u> We were reminded to "trust but verify" our new vendors especially before awarding multiple procurements. There were some components that required welding of pieces that were pre-beveled (a.k.a. weld prepped). We did not require a hold inspection on these components and the vendor proceeded to weld the joints without pre-inspection. Once the hardware was received and inspected by PPPL, we discovered that the material welded had not been properly prepared. PPPL had to grind away and re-weld questionable joints. (See "Procurement Lessons Learned Causal Analysis Report" under review documents.)
   - Next time: Ensure inspection hold points are written into contracts for all critical welds but especially with new vendors. Additionally, more thorough vetting of our vendors.

4. <u>Loss of key personnel:</u> Loss of our DCPS CAM (due to his sudden death) as well as the temporary loss of the Magnet CAM (due to lengthy illness) resulted in impacts to the project schedule as other stepped up to "fill-in". The secondary imp[act was an increase

in project cost as lesser experience personnel took longer to come up to speed and carry on the work.

- Next time: Cost and schedule risks for loss of key personnel must be more thoroughly analyzed.

Top 3 Successes:

From the folder of "let's not forget" there are 3 major successes that stand out.

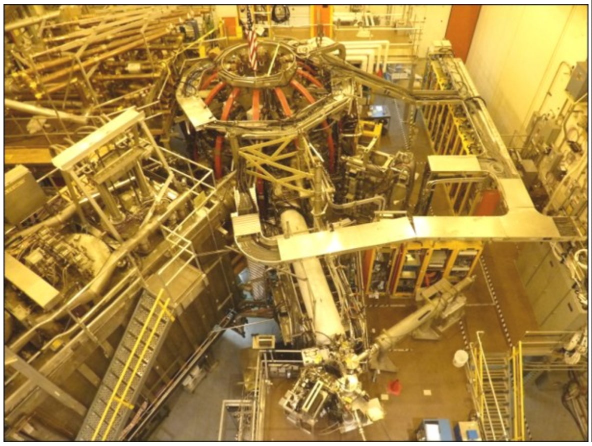
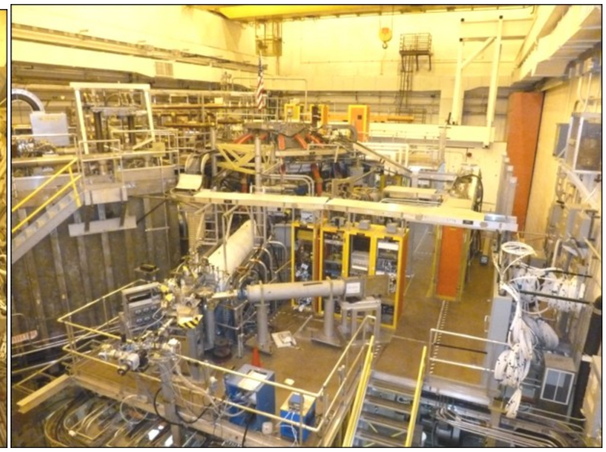
1. Safety: The attention to worker safety resulted in only 5 minor reportable minor injuries in over 550,000 hours worked. While we have a robust safety organization and up front Management buy-in, it came down to people not taking risks or short cuts in the name of schedule or cost. The safety culture at PPPL is one of its strongest assets.

2. Supervision: Work control center provided real value in establishing daily communication and coordination of field activities. Support needs (QC weld inspections, Safety support for walk downs, Health Physics) were determined in this daily 10 minute meeting. This process was established during the TFTR D&D project which was successful in finishing safely on schedule and $3.6M under budget.

3. Technology Risk: Technology Risk: The project was not risk adverse on employing new processes or technologies to provide engineering solutions. The project utilized 7 fabrication and assembly techniques that benefited the construction of the new center stack magnet and vessel upgrade; (Ref Appendix K for detailed presentation)
   1. Friction stir welding of copper was used to join high strength to high conductivity copper grades in the TF center bundle conductors.
   2. A new non-ionic soldering process was developed.
   3. Wire Electric Discharge Machining (EDM) was used in the manufacture of the critical TF High-Current Connector.
   4. A carefully planned Vacuum Pressure Impregnation (VPI) process with hard metal molds were used to assure the strength and electrical integrity of the center stack.
   5. Cyanate Ester / Epoxy Resin was chosen because of its maintenance of strength at elevated temperature.
   6. Electron Beam Welding was used to manufacture the TF Lead Extensions and Passive Plate expansion connectors.
   7. A water-soluble casting material, "Aquapour", was used to maintain a thermal expansion gap between the center stack TF and OH winding. This process proved beneficial in winding the CS OH conductor, however, we were not able to remove the aqua pour as planned due to it being impregnated with epoxy. This setback resulted in a critical path schedule delay and will impose additional operational considerations. This presented PPPL with a sobering lesson learned opportunity.

8. PHOTOS

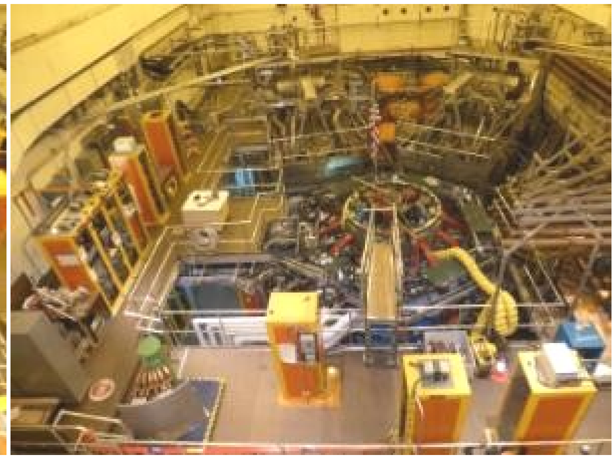
Overview of NSTXU Test Cell – Erik Perry

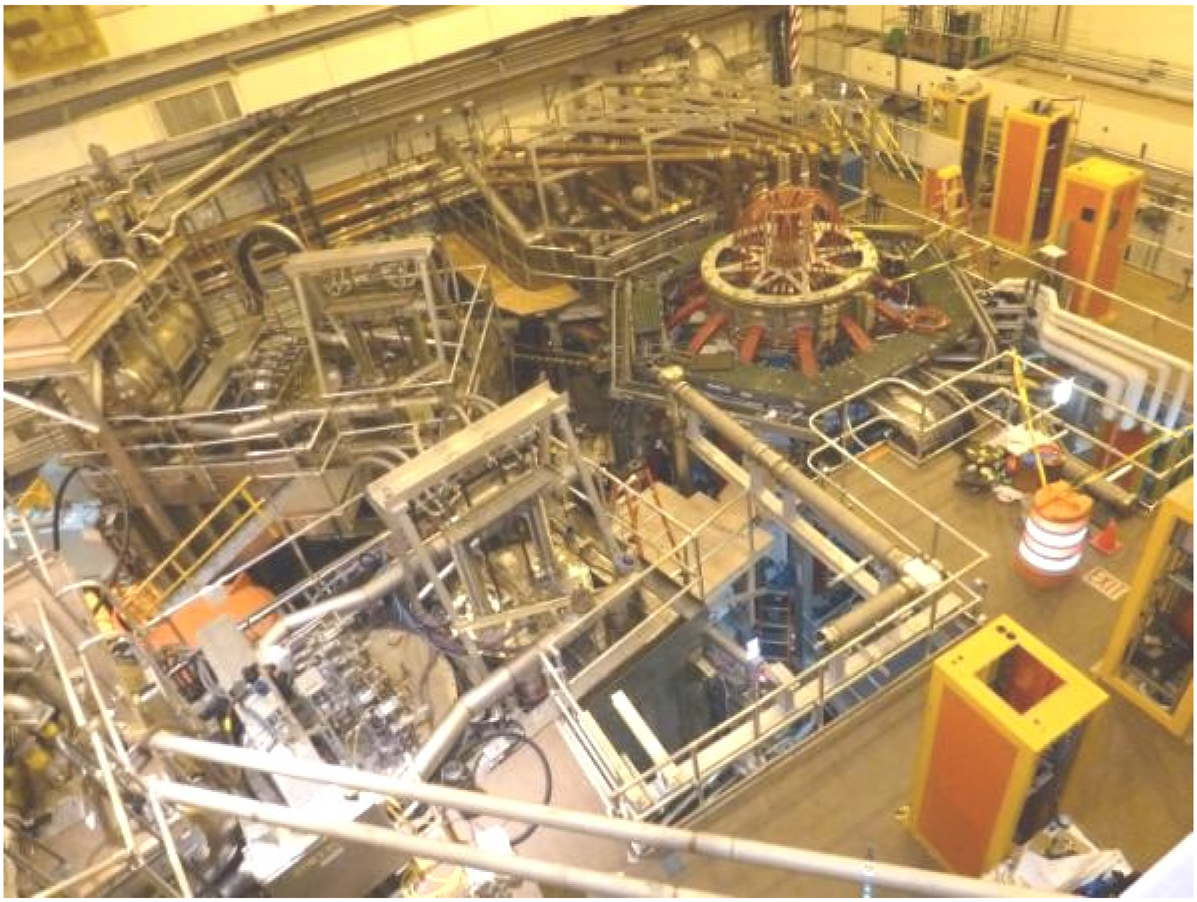
October 2011


October 2012


October 2013



October 2014

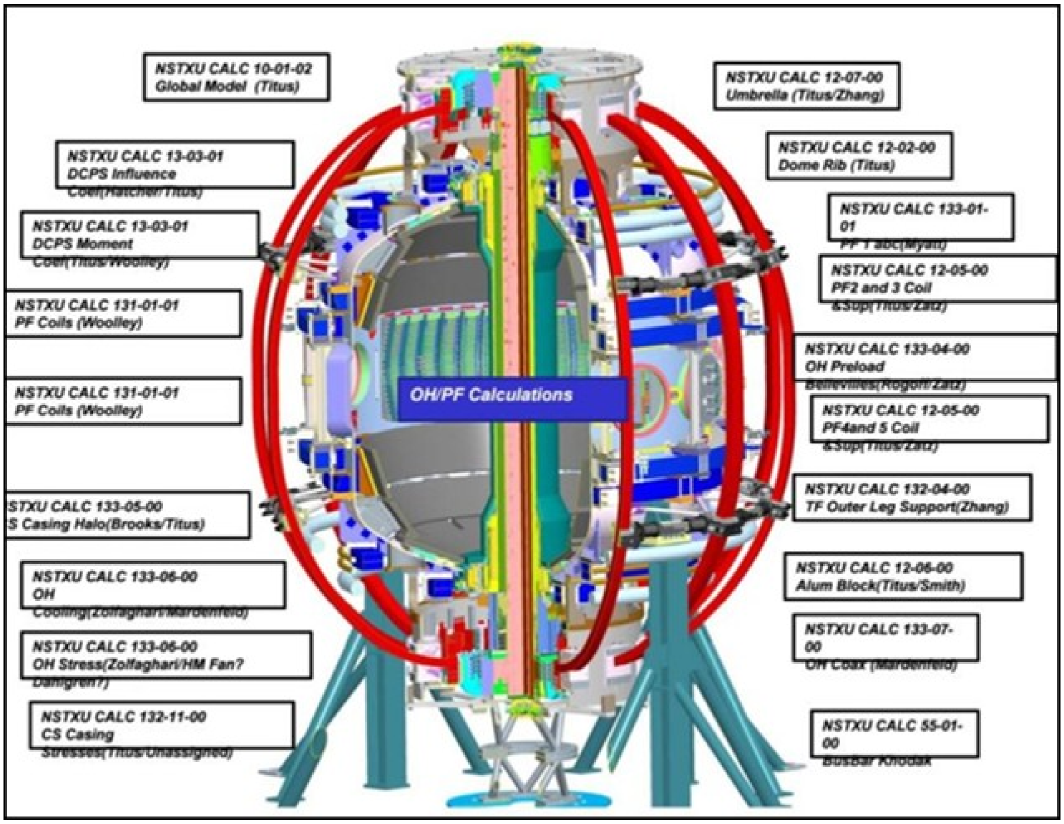


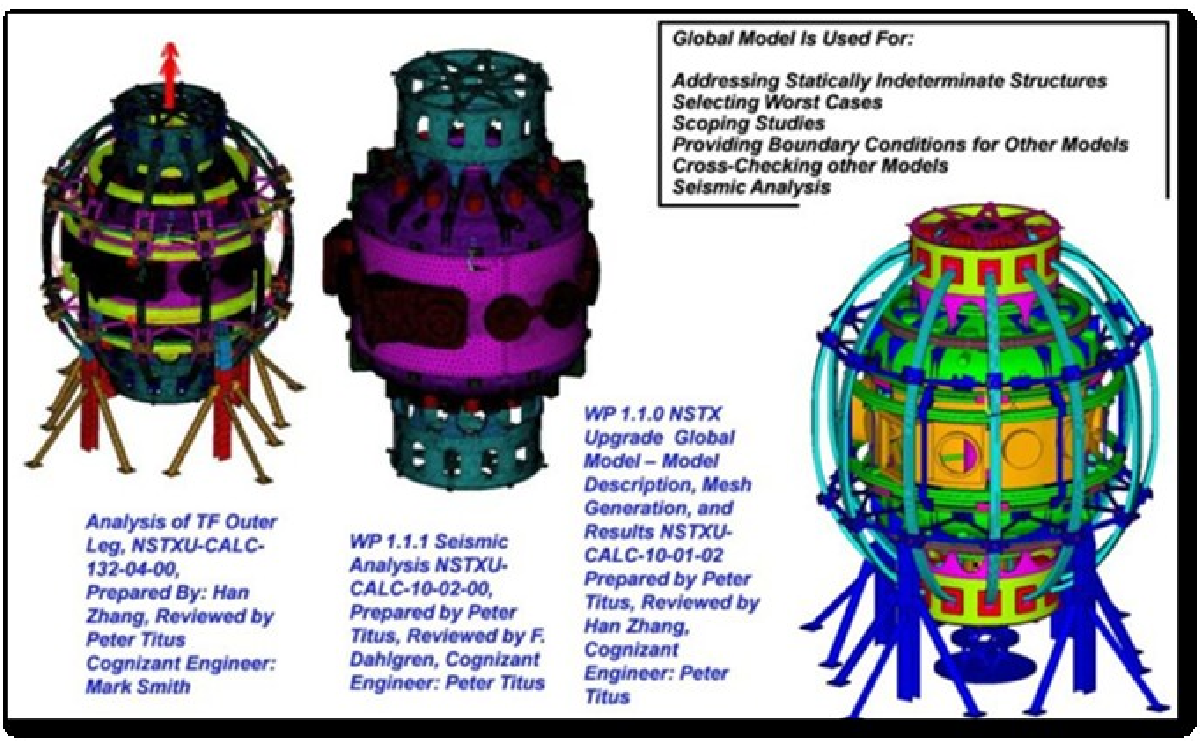
April 2015

<u>1.1 Torus Systems</u>

<u>1000 CSU Analytical Support – Pete Titus</u>

Calculations required to form the basis for designs





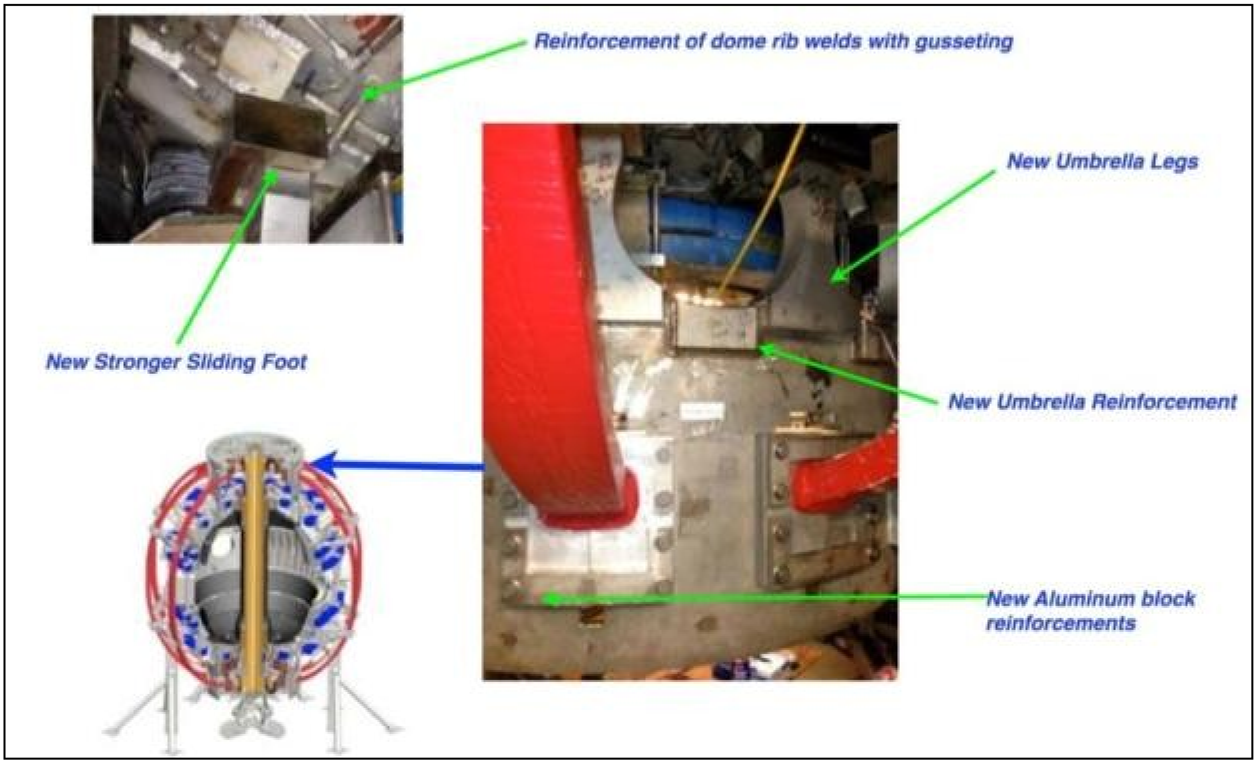
1001 CS Plasma Facing Components – Kelsey Tresemer

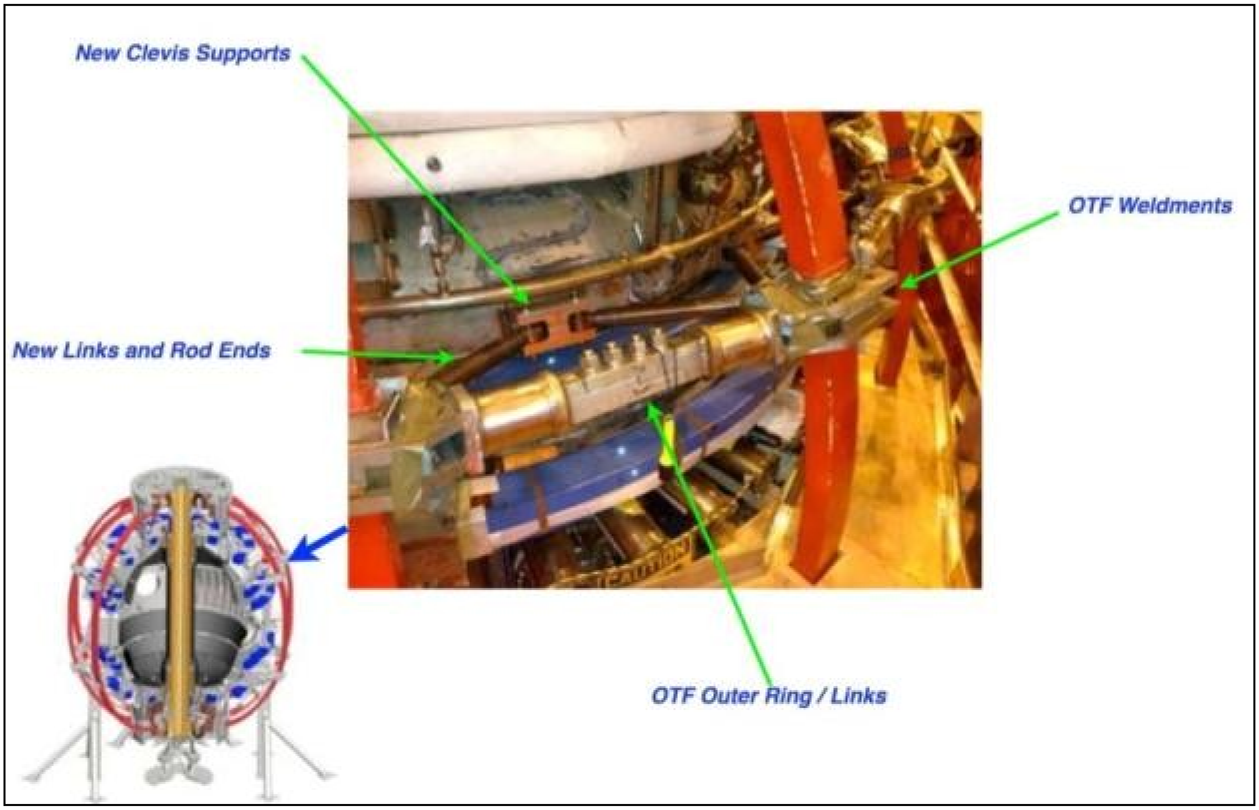
Plasma Facing Component (PFC) tiles installed on the centerstack casing

- Challenge: The existing secondary plates in the Bay A/L were weakene(by the thermal cycle during brazing.
- Hardness and tensile test results confirmed that these plates are significantly weaker than the standa plates.
  - Standard (unbrazed) plates = 57 ksi (tensile strength)
  - PCHERS Passive Plate braze joint = 7 k
  - Electron beam weld joint = 40 ksi
  - E-beam Heat affected area = 57 ksi

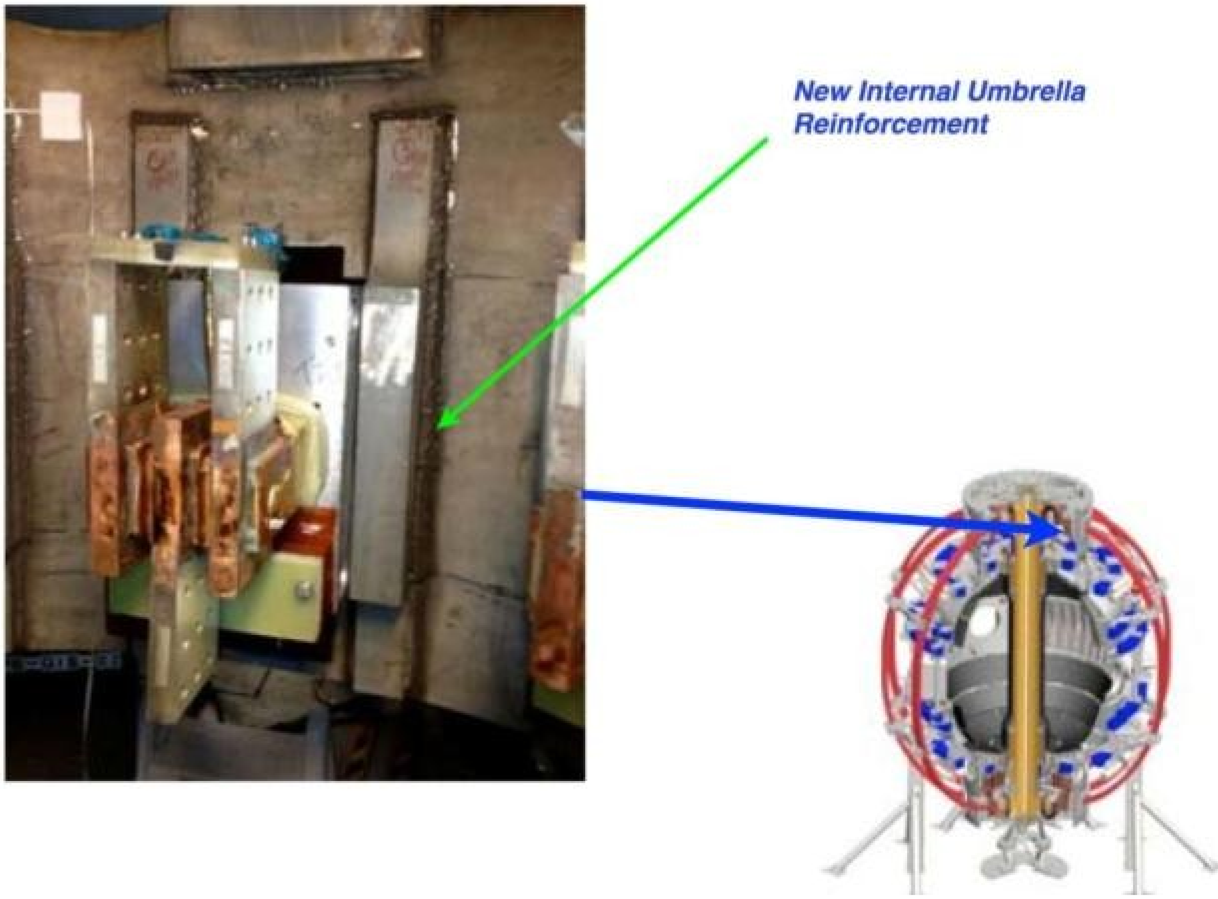
A new Design used E-Beam welding to join the passive plates to the jumpers

1200 Structures & Supp – Mark Smith





1200 Structures & Supp (continued)



More robust umbrella legs designed

<u>**1300 Center Stack**</u>
<u>**1301 Outer TF Coils**</u>

Two new outer TF coils fabricated and installed

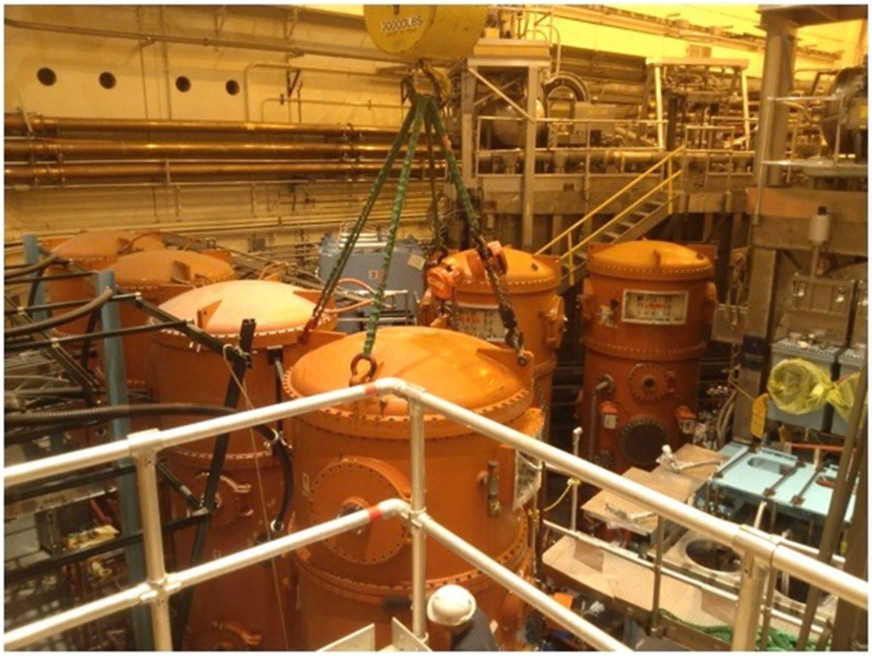
See Section I for detail photos on the Centerstack Fabrication and Assembly

2420 2nd NBI Sources – Tim Stevenson

Beamline 2 Box Lift **Beamline 2 Lid Lift**

NBI BL Alignment

2425 BL Relocation (continued)



High Voltage Enclosures (HVE's) Relocated

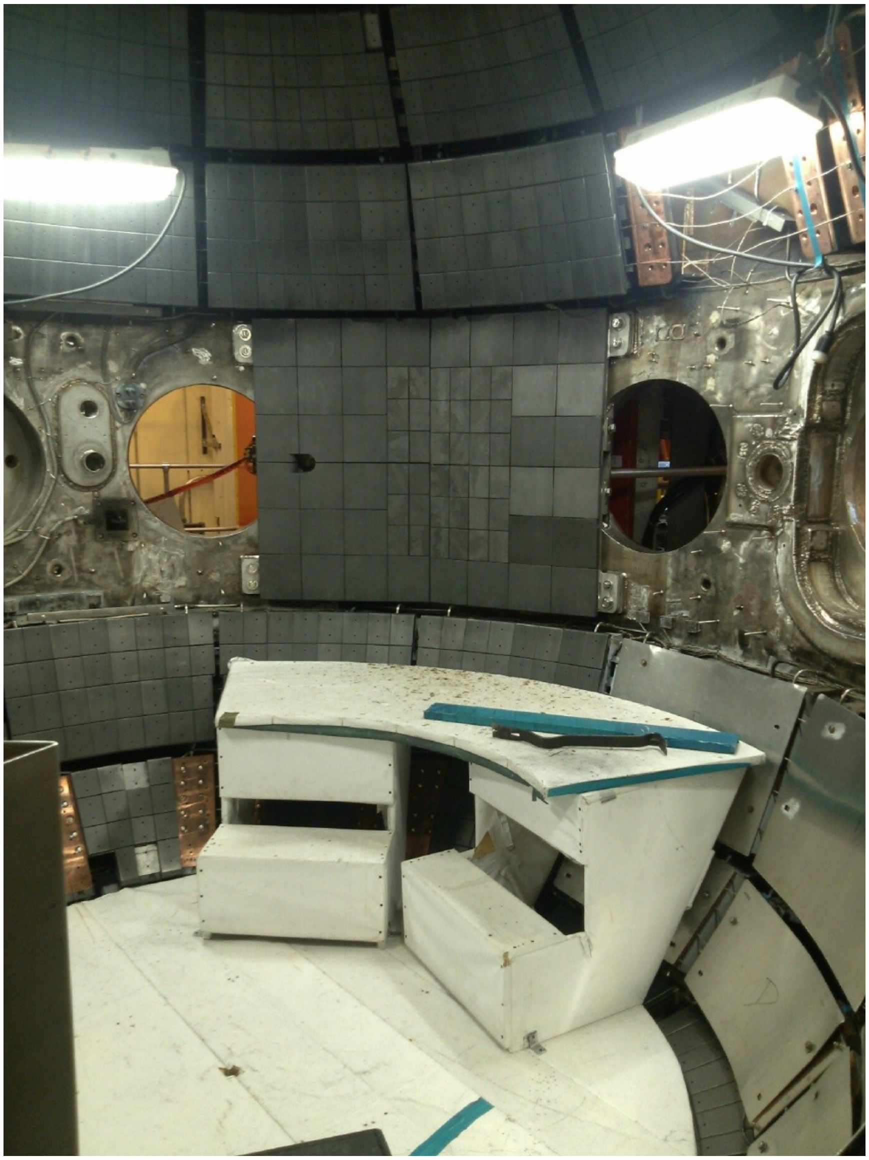
Transmission Lines Installed

Box decon from lift and from source platform using 25 gallon sprayer and DI water

2450 2nd NBI Services – Mark Cropper

Cryogenic LN and LHe Piping installed

NBI Deionized Water Piping Installed



NBI Armor Installed

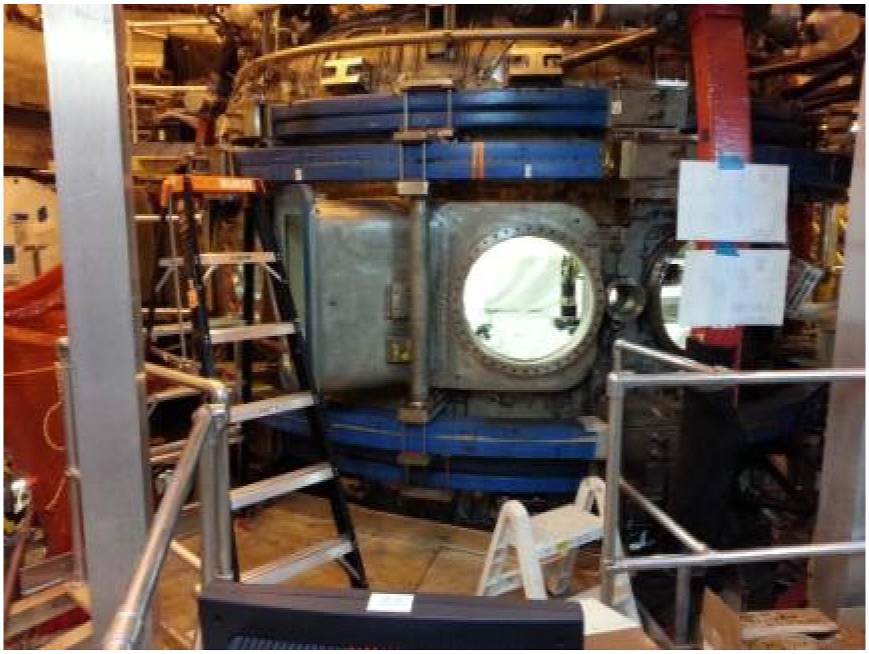
Power Cables in TCB,TTC to NTC Installed

2475 2nd NBI Controls – Mark Cropper

Local Control Center and wiring updated

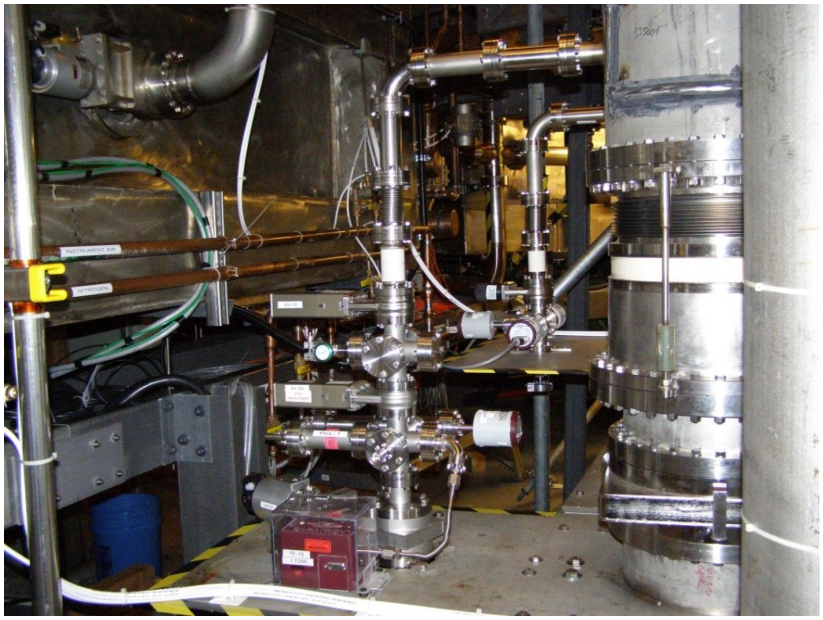
PLC Gallery Racks, Chassis, software, Cabling Completed

2480 2nd NBI/TVPS Duct – Mark Cropper



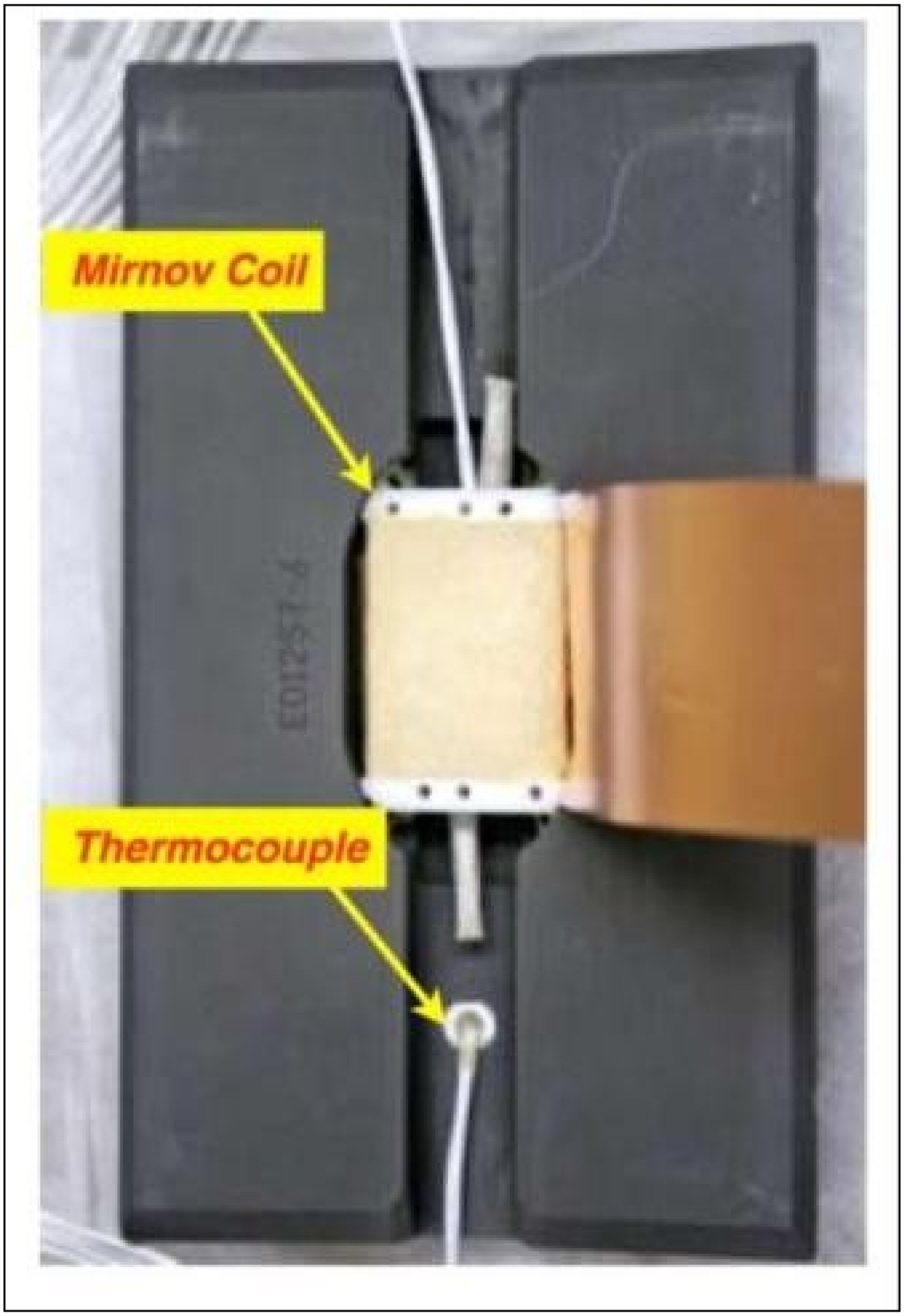
NBI Duct Installed

<u>**2485 Vacuum Pumping System – Bill Blanchard, Mark Cropper**</u>



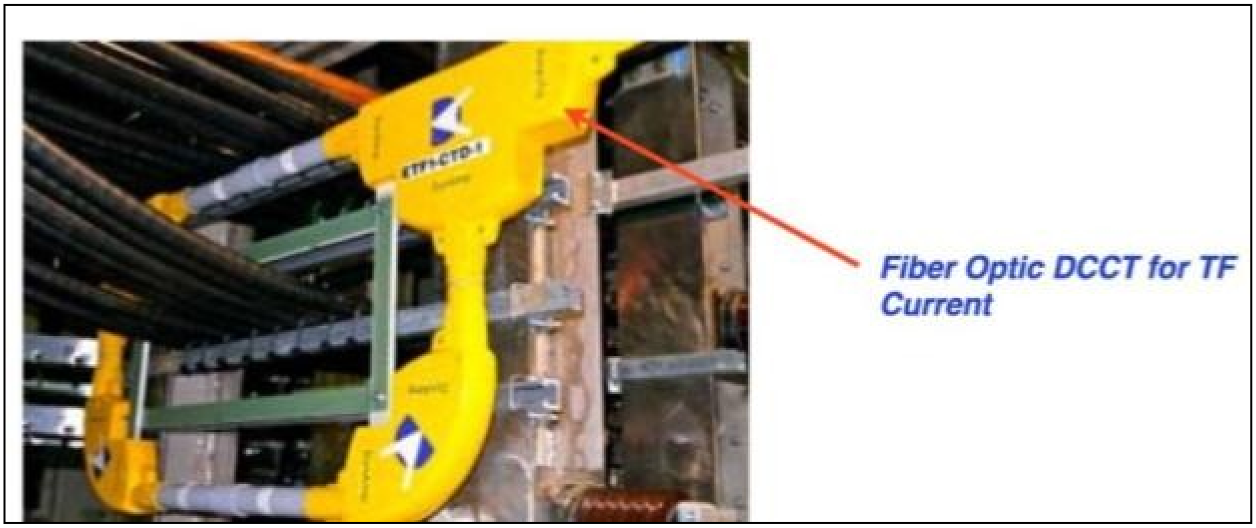
Torus Vacuum Pumping System Installed

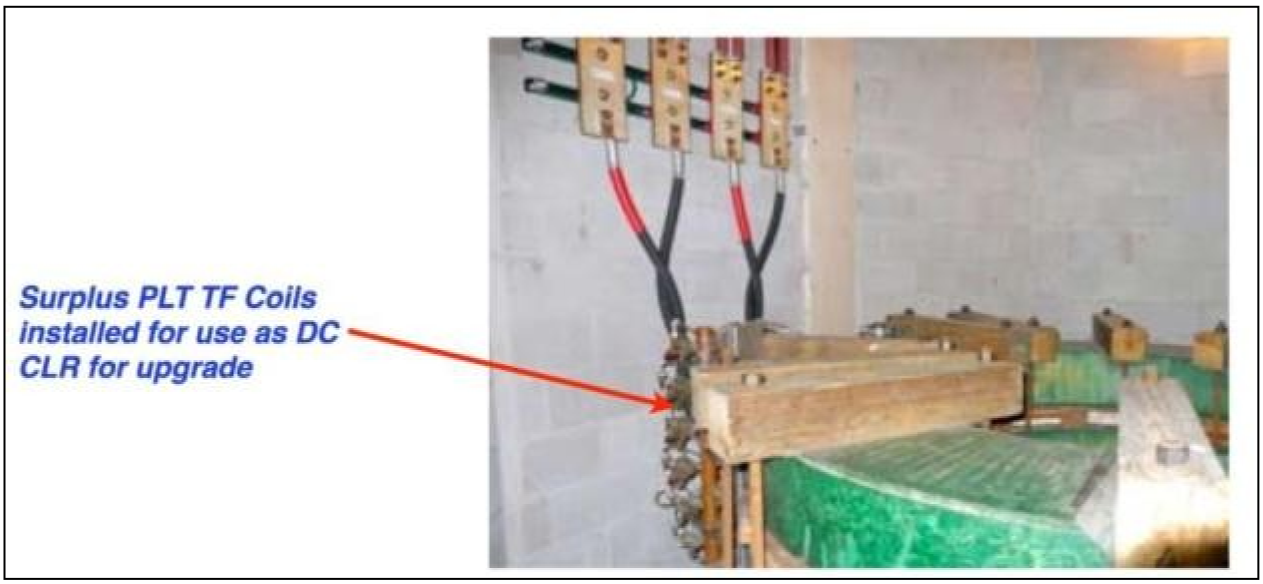
1.4 Plasma Diagnostics – Bob Kaita



Mirnov coils and Rogowski coils installed into the PFC tiles

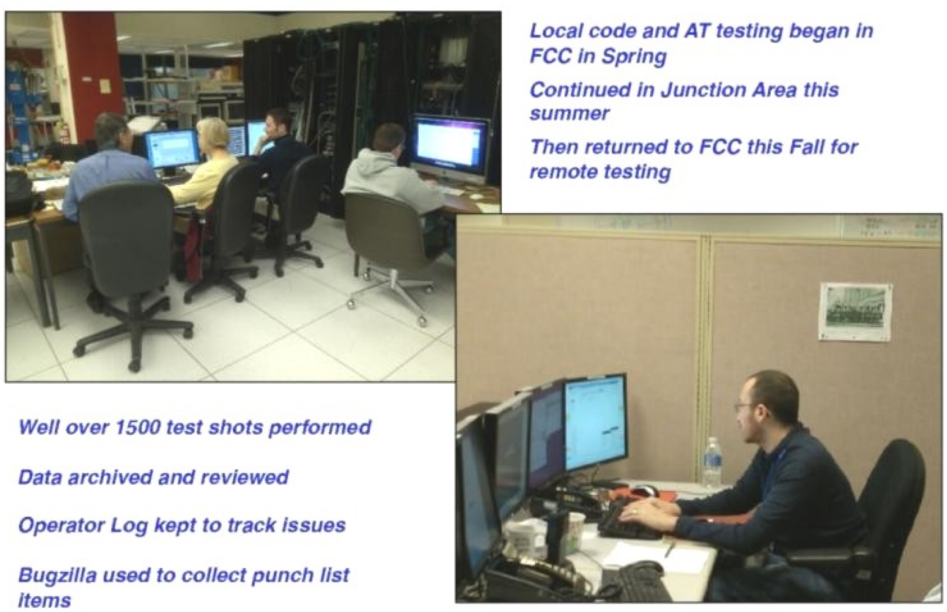
1.5 Power Systems
5000 CSU Power Systems (Raki)





<u>**5200 DCPS (Stevenson)**</u>

DCPS Autotester Interface Panel
Allows local testing of DCPS code



Testing of DCPS with Autotester

5200 DCPS (Stevenson)

Board testing and bench testing of DCPS hardware

Junction area DCPS hardware user interface installed

5200 DCPS (Stevenson)

HSCs
RTU
HUI
AIO/DIO
DCPS AT computer
DCPS-RT1 computer
Data Server
UPS

Interface testing in progress

First use of DCPS-JA will be in support of rectifier dummy load testing using OI and Ft limits

Experience will be gained with operability and operations protocols prior to ISTP and CD-4

Junction area DCPS complete

Redundant code using PCS inputs from FPDP data stream

Set slightly more restrictively than DCPS-JA to avoid L1

Same core code in both locations

DCPS core software testing completed

DCPS PCS Integration in progress

Testing found OS kernal problem

Concurrent computer out for recovery

DCPS fcc running on "Warthog" for testing

On track for CD-4...

DCPS FCC residing on PCS-SRV-1

5501 Coil Bus Runs (Atnafu)

Inner TF bus bar

1.8 Assembly
8200 /8250 Machine installations and assembly – Erik Perry


Lower Passive plates being installed


Outer TF to Umbrella connection **New outer TF coil being installed**

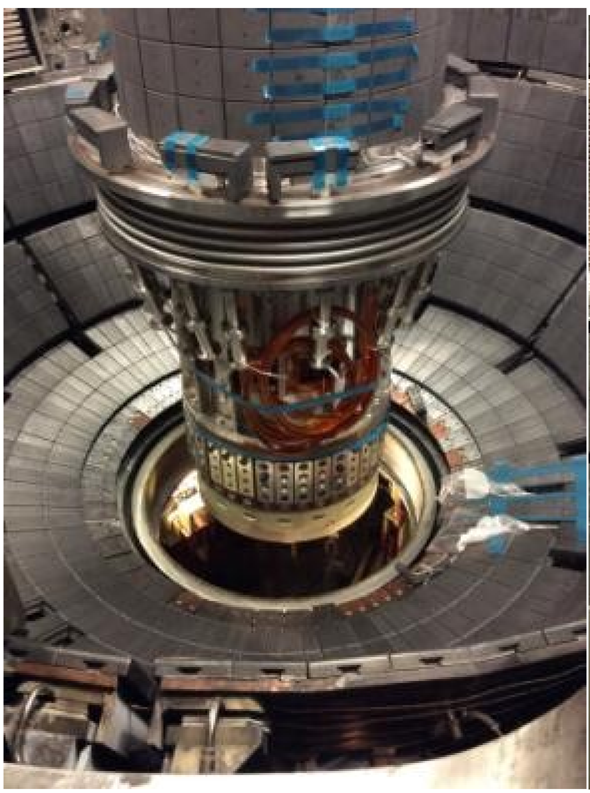
8200 /8250 Machine installations and assembly – Erik Perry (continued)

Outer TF Leg turnbuckle supports

Umbrella legs upgraded from 5/8” to 2” thick

8200 /8250 Machine installations and assembly – Erik Perry (continued)

CS Casing being installed over TF/OH bundle **CS assembly being lifted into the machine**



New Centerstack installed

9. PROJECT DOCUMENT ARCHIVES AND LOCATIONS

Project documents are archived in the NSTXU database at http:// http://nstx-upgrade.pppl.gov/

Please contact Steve Langish or Ron Strykowsky for assistance

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slangish@pppl.gov ***rstrykow@pppl.gov***
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Princeton, NJ 08543-0451
GPS: 100 Stellarator Road
Princeton, NJ 08540 U.S.A.

Appendix A

Detailed WBS Dictionary

WBS Element: 1 **WBS Level: 1**

WBS Title: NSTX Upgrade Project

Definition: The replacement of the entire Center Stack Assembly (CSA) and installation of a second Neutral Beam Injection (NBI) system on NSTX is planned to allow an improved understanding of the Spherical Torus (ST) magnetic confinement configuration which is needed to establish the physics basis for next-step ST facilities, broaden the scientific understanding of plasma confinement for ITER, and maintain U.S. world leadership in ST research capabilities. In particular, operation at higher magnetic field with reduced plasma collisionality is needed to extend the plasma physics understanding of the ST toward next-step ST facilities and ITER. Controllable fully-non-inductive current-drive will also contribute to assessing the ST as a potentially cost-effective path to fusion energy.

WBS Element: 1.1 **WBS Level: 2**

WBS Title: Torus Systems

Definition: The torus systems include all the systems and related elements within the boundary of the NSTX support structure. This WBS element includes the Plasma Facing Components (WBS 1.1), Vacuum Vessel & Support Structure (WBS 1.2), and Magnet Systems (WBS 1.3). The scope of the work contains engineering design, R&D, mockups, procurement activities, and component fabrication. Assembly of the Torus System is included in WBS 1.8.

WBS Element: 1.1.0 **WBS Level: 3**

WBS Title: Project Integrated Model

Definition: This WBS element includes development of a project integrated model and the associated analysis support of the overall NSTX Upgrade Project.

As a result of the NSTX Upgrade Project, the NSTX global models and analyses will need to be updated. This WBS element includes analytical support for global models and analysis not presently identified. The global model will provide the basis for updating the analysis to qualify components and identify areas of the tokamak requiring further analysis. Identified plasma scenarios and power supply current limit analyses will be run in the global model and current sets that require further analysis will be identified. These analyses also serve to check the results of more detailed analyses.

{Center Stack Upgrade (CSU) analytical Support (Job 1000)}

WBS Element: 1.1.1 **WBS Level: 3**

WBS Title: Plasma Facing Components

Definition: The plasma facing components (PFCs) include all the systems and related elements that serve to protect the vacuum vessel from the charged particles and radiation flux from the plasma. These include the plasma facing tiles and mounting components, passive stabilizers, inner wall protection, divertor area strike plates, and local I&C. This element consists of the engineering design, analysis, procurement activities and component fabrication.

The NSTX Upgrade Project will require new PFCs on the new Center Stack Casing (CSC) and the new Inboard divertor (IBD). This WBS element includes the design and analysis for both the CS and IBD PFCs, design modifications to the PFC tiles to accommodate surface diagnostics, including design of the tile mounting schemes and routing plans for diagnostic wires, generation of required documentation such as checked calculations, specifications and procedures, the procurement and installation of all PFC tiles and hardware on the CSC and IBD.

{Center Stack Upgrade (CSU) PFCs (Job 1001)}

In addition the NSTX Upgrade will require analysis of the passive plates for disruption and thermal loads. CDR level calculations were performed that addressed one of five disruptions. The remaining identified disruptions are to be completed during Preliminary Design. During Final design, analysis updates are expected as a result of preliminary design evolution. Modest hardware upgrades are anticipated as part of this task. Additions of accelerometers or other diagnostics to benchmark calculations with actual performance in NSTX are also anticipated. This analysis effort is included in this WBS element.

{Passive Plate Analysis and Upgrade Activity (Job 1002)}

With the exception of the modifications identified above, no additional modifications to the PFCs are anticipated.

WBS Element: 1.1.2 **WBS Level: 3**

WBS Title: Vacuum Vessel and Support Structure

Definition: The vacuum vessel & support structure (VVSS) consists of the vacuum chamber, not including the PFCs, all ports and vacuum boundary closures and the torus support structure which provides the overall supporting mechanism for the torus components to the test cell floor. This WBS element includes the engineering design, analysis, procurement activities and component fabrication.

The NSTX Upgrade Project will require that the existing VVSS be modified to accommodate the new center stack structure, including the umbrella structure and the new center stack support structure. This WBS element includes the analytical and CAD design of the support structures associated with the Magnet upgrade activities. The scope includes; the Vacuum Vessel & Structural Support, the Outer TF Structures, the Outer PF Coil Structures, the Umbrella Structural Reinforcement, the CS Support Pedestal and miscellaneous Vacuum Vessel Structural Supports. It also includes the procurement and fabrication of these structures, but does not include installation costs. Installations costs are included in WBS 1.8. {Vacuum Vessel & Support Structure (Job 1200)}

WBS Element: 1.1.3 **WBS Level: 3**

WBS Title: Magnet Systems

Definition: The magnet system consists of the outer Poloidal Field (PF) coils (PF#2-5), the outer Toroidal Field (TF) coil legs, and the Center Stack Assembly (CSA). The CSA contains the inner TF coil legs, the TF coil joint (flex bus assembly), the OH solenoid, the shaping coils, and the center stack casing. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication of the magnet systems up to and including the magnet system coil buswork, but does not include installation costs. Installations costs are included in WBS 1.8

The NSTX Upgrade Project will require engineering, analysis, design procurement and fabrication of a new CSA, replacement of two outer TF coil legs, and a fabrication of a new TF coil joint

This WBS element provides CAD design support for the overall assembly drawings associated with the CSA upgrade. It also includes some time for space allocation studies associated with the magnet upgrades. CAD design support for individual components is included in the specific component jobs.

{Center Stack Upgrade Project Design Support (Job 1300)}

{Center Stack Upgrade Magnet Systems for Conceptual and Prelim Design (Job 1310)}

WBS Element: 1.1.3.1 **WBS Level: 4**

WBS Title: Outer Poloidal Field Coils (PF #3-5)

Definition: The outer Poloidal Field coils (PF 3-5) consist of 5 poloidal field coils PF 3 upper and lower, PF 4 upper and lower and PF 5 upper and lower. There are no changes to the outer PF coils as part of the NSTX Upgrade Project scope.

WBS Element: 1.1.3.2 **WBS Level: 4**

WBS Title: Outer Toroidal Field Coils

Definition: The outer Toroidal Field coils subsystem consists of the coil sections that make up the 12 TF outer legs. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication. For the NSTX Upgrade Project two (2) new Outer TF coils will be fabricated to replace existing ones. This WBS element includes the fabrication of (2) new Outer TF coils to replace the existing leaking OTF#7 and OTF#11 that will be removed during the Neutral Beam port upgrade. This coil will then be used as a spare for future operations in NSTX. The scope includes the procurement of conductor, insulation material, aluminum castings and supports necessary to fabricate a new OTF coils. Coil fabrication will be performed by an outside vendor. This scope does not include costs associated with installation. Installations costs are included in WBS 1.8

{Outer Toroidal Field Coil Repairs (Job 1301)}

WBS Element: 1.1.3.3 **WBS Level: 4**

WBS Title: Center Stack Assembly (CSA)

Definition: The CSA consists of the inner TF coil legs, the OH solenoid, the inner PF shaping coils [PF1a, 1b and 1c], and the center stack casing. Also included in this WBS element are the TF coil joint (flex bus assembly) and the ceramic break assembly. The scope of this WBS element includes the design, analysis, prototypes (as required), procurement activities, fabrication and assembly of the Center Stack.

WBS Element: 1.1.3.3.1 **WBS Level: 5**

WBS Title: Center Stack - TF Inner Legs/Bundle

Definition: The TF inner leg subsystem consists of the new coil sections that will make up the TF inner bore and bundle. Also included in the scope of this WBS element is the TF coil joint (flex bus assembly) and testing of the new TF coil joint design.

For the NSTX Upgrade Project a new TF Inner Leg will be fabricated. This WBS element includes the design of the TF Bundle, the TF flex bus and flex bus supports and includes all analytical and CAD design efforts for these components. It also includes the early procurement of the TF conductor [80 lengths] and procurement of the TF flex bus and supports. It does not include the procurement/fabrication of the Inner TF bundle, which is included as part of the OH procurement in WBS 1.1.3.3.2.

{Inner Toroidal Field Bundle (Job 1304)}

. For the NSTX Upgrade Project a test stand to measure the required performance parameters on the new NSTX TF joint design will be designed and fabricated. Test parameter measurements and cyclic lifetime tests of the new TF joint materials will be performed and testing data will be compiled.

{TF Joint Stand & Performance Test (Job 1303)}

WBS Element: 1.1.3.3.2 **WBS Level: 5**

WBS Title: **Ohmic Heating Solenoid**

Definition: The ohmic heating solenoid subsystem consists of the new coils that will make up the center solenoid. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication.

For the NSTX Upgrade a new OH Solenoid will be fabricated. This WBS element includes the design & fabrication of a new OH solenoid and associated components including a Belleville washer spring assembly and support structures for the NSTX upgrades. It also includes all analytical & CAD design efforts. Includes advance procurement of the copper conductor and co-wound [glass/Kapton] insulation. Also includes the procurement of the Micro-therm insulation, conductive paint.
Includes the in-house fabrication for the combined OH and TF bundle assembly. A single vendor will fabricate both components.
{Ohmic Heating Solenoid (Job 1305)}

WBS Element: **1.1.3.3.3** **WBS Level: 5**

WBS Title: **Inner Poloidal Field Coils**

Definition: The inner poloidal/shaping coils subsystem consists of the new coils that will make up the poloidal field coils 1A, 1B and 1C. This WBS element includes the design, analysis, prototypes (as required), procurement activities and fabrication.

For the NSTX Upgrade three new sets of inner poloidal field coils will be installed. This WBS element includes the design and procurement of the Inner poloidal field coils and supports which includes all analytical and CAD design efforts for these components. It includes the early procurement of the PF conductor and co-wound [Glass/Kapton] insulation.

{Inner Poloidal Field Coils (Job 1306)}

WBS Element: **1.1.3.3.4** **WBS Level: 5**

WBS Title: **Center Stack Casing and Assembly**

Definition: This WBS element includes the design and fabrication of the Center Stack casing and ceramic break assembly for the upgraded Center Stack as well as the assembly of the new Center Stack.

The Center Stack Casing effort includes analysis and CAD design for the casing components; the procurement of the Inconel tubing, forgings, bellows and organ pipes; the fabrication of Center Stack support legs; the procurement/fabrication of a new ceramic break assembly; the in-house assembly of the casing components; and mounting of the PF1A and PF1B structure/coils to the casing.

{CS Casing (Job 1307)}

The Center Stack Assembly effort involves all activities associated with the assembly of the Center Stack and includes design modifications and upgrade of the coil assembly stand; procedures for assembling the Center Stack and for installation; assembly of the Center Stack components including the OH/TF coil supports, mounting of the OH Solenoid surface diagnostics and thermal blanket, inconel casing and inner PF coils and setup and tear down of the Center Stack assembly area.

{Center Stack Assembly (Job 1302)}

WBS Element: 1.2 **WBS Level: 2**

WBS Title: Plasma Heating and Current Drive Systems

Definition: The heating and current drive systems include all the auxiliary plasma heating and current drive systems. This WBS element includes the High Harmonic Fast Wave (HHFW) Current Drive System, the Coaxial Helicity Injection (CHI) Current Drive System, the Electron Cyclotron Heating (ECH) System, and the Neutral Beam Injection (NBI) System. Only ECH (WBS 1.2.3) and Neutral Beam Injection (WBS 1.2.4) are impacted by the NSTX Upgrade Project. The scope of the work contains engineering design, R&D, mockups, procurement activities, component fabrication, installation, and System Testing. Installation of the WBS 2 systems is included in the individual WBS 2, level 3 elements.

WBS Element: 1.2.1 **WBS Level: 3**

WBS Title: High Harmonic Fast Wave (HHFW)

Definition: The High Harmonic Fast Wave System provides radio frequency (RF) energy to the plasma for the purpose of plasma heating and current drive. The components of such a system include generators, transmission lines, tuning systems, antennas and their associated diagnostic and control systems. The system includes components inside the vacuum vessel (antennas and feed-throughs) in the test cell (transmission and tuning components) and in the RF power rooms (AC/DC power conversion system, RF generators, switches and loads). There are no changes to the HHFW System as part of the NSTX Upgrade Project.

WBS Element: 1.2.2 **WBS Level: 3**

WBS Title: Coaxial Helicity Injection (CHI) Current Drive

Definition: The Coaxial Helicity Injection System is to provide helicity injection to aid startup and provide edge current profile control. The main hardware elements required fall under other WBS's. These include a ceramic break in the vacuum vessel (WBS 1.1.3) the poloidal coil system (WBS 1.1.3) and a power supply (WBS 1.5). In this WBS element the task is to assure that the various components of the system are compatible with helicity injection and that the Central I&C required is provided. There are no changes to the CHI System as part of the NSTX Upgrade Project.

WBS Element: 1.2.3 **WBS Level: 3**

WBS Title: Electron Cyclotron Heating (ECH)

Definition: The Electron Cyclotron Heating System provides breakdown and startup assist through an electron cyclotron heating system. The system will be composed of an AC/DC power conversion system, gyrotron source, transmission system, vacuum window and launcher. Any ECH specific diagnostics will be included and interfaced to Central I&C.

This scope of the WBS element for the NSTX Upgrade covers the ECH and other antenna systems, and miscellaneous diagnostics and components attached to the vessel which will be affected by the increases in EM and thermal loading. Disruption loads on the ECH waveguide will be evaluated for the Center Stack Upgrade Fields and field transients. Discussions with heating system experts regarding the performance of the ECH system for the higher Center Stack Upgrade fields indicate that no modification to the resonant frequency or other operational characteristic for the system will require upgrade. Only disruption qualification is planned. No previous qualification has been identified, so the resources include creation of a new calculation – not a review of an existing calculation as is the case for ICRH.

{Electron Cyclotron Heating (Job 2300)}

WBS Element: 1.2.4 **WBS Level: 3**

WBS Title: Neutral Beam Injection (NBI)

Definition: The Neutral Beam Injection System Upgrade provides a second Neutral Beam as part of the NSTX Upgrade Project. The second NBI is identical to the one already installed on NSTX. An existing TFTR beam will be decontaminated, refurbished, and installed on NSTX. This WBS element includes the NBI source refurbishment; the TFTR beamline decontamination, refurbishment and relocation to the NSTX Test Cell; the 2nd NBI Services; the NBI armor modifications; the 2nd NBI Power, Controls and Instrumentation; the 2nd NBI Duct and vacuum vessel modifications; and the NSTX Test Cell equipment removals and relocations necessary to accommodate the 2nd NBI. Vacuum Pumping System Modifications necessary to accommodate the 2nd NBI are included in WBS element 1.3. NBI Management and Health Physics support are included in element WBS 1.7.

WBS Element: 1.2.4.2 **WBS Level: 4**

WBS Title: NBI Source Refurbishment

Definition: This WBS element includes the activities to refurbish three neutral beam ion sources for the 2nd Neutral beamline, as currently being performed for the installed Neutral beamline 1.

{Source Refurbishment (Job 2420)}

WBS Element: 1.2.4.3 **WBS Level: 4**

WBS Title: NSTX Beamline 2 Decontamination

Definition: This WBS element includes the disassembly and decontamination activities of a TFTR Neutral Beam beamline in preparation for beamline refurbishment and reuse as an NSTX upgrade.

{NSTX Beamline 2 Decontamination (Job 2430)}

WBS Element: 1.2.4.4 **WBS Level: 4**

WBS Title: NBI Beamline Refurbishment and Relocation

Definition: This WBS element includes refurbishment of a TFTR NBI and its relocation to the NSTX test cell.

Included in this WBS element are the activities necessary to refurbish a TFTR Neutral Beam beamline for use on NSTX. This scope includes replacing the ion dump and calorimeter bellows as required and refurbishment of the seals, thermocouple wiring, and bellows (cal and spool) as needed.

{NSTX Beamline 2 Refurbishment (Job 2440)}

Also included in this WBS element are the efforts necessary to relocate a TFTR neutral beam line and ancillary equipment into the NSTX test cell. This includes High Voltage Enclosures (HVEs) and the complete beam box and components.

{NSTX Beamline 2 Relocation (Job 2425)}

WBS Element: 1.2.4.5 **WBS Level: 4**

WBS Title: NSTX Beamline 2 Services

Definition: This WBS element includes the efforts to provide services to the new neutral beam beamline and ancillary equipment in NSTX test cell. These services include water, cryogenic systems, gas supplies, and vacuum lines.

{NSTX Beamline 2 Services (Job 2450)}

WBS Element: 1.2.4.6 **WBS Level: 4**

WBS Title: NBI Armor

Definition: This WBS element includes the design, fabrication, and installation of upgraded and relocated neutral beam armor including cooling and instrumentation work.

{NBI Armor (Job 2460)}

WBS Element: 1.2.4.7 **WBS Level: 4**

WBS Title: **NBI Beamline 2 Power and Controls**

Definition: This WBS element includes providing power, controls and instrumentation for the 2nd Neutral beamline.

Included in this WBS element is providing power for the NBI beamline 2. NB2 is planned to be powered from the TFTR NB4 A, B, & C line ups. The electrical equipment in these line ups will be reactivated. The TFTR NB4 HVEs will be relocated to the NSTX Test Cell as part of WBS element 1.2.4.4. New triax cables will be installed with terminations from the Modregs to the HVEs. New Decel coaxial cables will be installed from the Decel supplies to the Sources. The Arc, Filament, Magnet, and the 208 feeds, to HVEs cables, will be spliced in the TFTR Test Cell basement to new cabling designed and installed from the TFTR Basement to the NSTX Test Cell. The fiber cables also will be spliced with additional lengths recovered from other TFTR line ups. The AC auxiliaries and Grounding for the NB2 will be designed and installed.

{NBI Power System (Job 2470)}

Also included in this WBS element are the controls and instrumentation for the NB2. The work covers PLC, programming, control racks, new thermocouples, TC scanner, miscellaneous controls, and control cabling. The work also includes the gradient grid upgrade. System integration and testing will also be performed as part of this effort.

{NBI Controls & Instrumentation (Job 2475)}

WBS Element: **1.2.4.8** **WBS Level: 4**

WBS Title: **NSTX Beamline 2 Duct & vacuum Vessel Modifications**

Definition: This WBS element includes the design, and fabrication of all components connecting the Neutral Beam Box to NSTX, and the connecting ductwork and modifications to NSTX Vacuum Vessel to accommodate the second beamline.

{NSTX NB2 Duct & VV Mods (Job 2480)}

WBS Element: **1.2.4.9** **WBS Level: 4**

WBS Title: **NSTX Test Cell Equipment Removals/Relocations**

Definition: This WBS element covers moving of racks and diagnostics to clear space in the NSTX Test Cell (NTC) for the second Neutral Beamline. Racks to be removed and re-installed in a new location are #419, 431-435, 440-445, 447-449, 488. Racks 456 and 489 will be removed and excess. This scope also includes the fabrication and installation of five sections of platform at elevation 118' on the west side of the NTC to accommodate the racks being re-installed in the NTC. Racks #441-445 will be relocated to the Gallery east of the NTC. Diagnostics to be removed are those from the midplanes of Bay J and Bay K as well as those on the present pump duct. The diagnostics from Bay J will be re-installed ~5" outboard of their present position. IR windows and the Transmission Grating Spectrometer will be relocated to the new NB duct. Ion gages, filaments and the RGA will be relocated to the new pump duct under the NB2 duct. SPRED and LOWEUS will be relocated to Bay L. The Thomson Scattering Beam Dump Window will be relocated to between Bays K and L.

{NTC Equipment Removals/Relocations (Job 2490)}

WBS Element: 1.2.4.0 **WBS Level: 4**

WBS Title: Vacuum Pumping System

Definition: The Vacuum Pumping System provides the source and distribution of all vacuum pumping to NSTX. This includes the roughing pumps as well as the turbo pumps and any backing pumps to:

- Provide the initial high vacuum environment with minimum impurities for plasma formation;
- Evacuate the spent plasma constituents at the end of each pulse prior to the next plasma pulse;
- Remove impurities liberated during bakeout and/or discharge cleaning of the vacuum vessel interior; and
- Provide instrumentation and a Residual Gas Analyzer.

This WBS element also includes the controllers for all pumps. The relocation of racks and control equipment is covered under WBS 1.2.4.9

In order to accommodate the installation of the 2nd NBI on NSTX the existing Vacuum Pumping System will be modified. This WBS element includes the design, fabrication, and installation of a new vessel pumping system and includes new pump ducts off of the Neutral Beamline 2 duct, mechanical and electrical isolation of the system, vacuum diagnostic relocation, magnetic.

{NSTX NB2 TVPS (Job 2485)}

WBS Element: 1.3 **WBS Level: 2**

WBS Title: Auxiliary Systems

Definition: This WBS element includes the Coolant Systems, the Bakeout Heating System, Gas Delivery System and the Glow Discharge Cleaning System. The scope of the work contains engineering design, procurement activities, component fabrication, and System Testing. Installation of the WBS 3 systems is included in the individual WBS 3, level 3 elements.

WBS Element: 1.3.2 **WBS Level: 3**

WBS Title: Coolant Systems

Definition: The Coolant System provides cooling water to remove heat generated from NSTX systems during experimental operations. The systems include the:

- TF/PF bus and coil cooling water system;
- Center stack cooling water system;
- Component cooling water system; and the
- Ohmic heating cooling water system.

These systems will provide cooling water for normal operations and discharge cleaning of the vacuum vessel. This WBS includes engineering design, analysis, procurement activities, component fabrication and installation to the coil, bus and component cooling manifolds at the torus.

The new Center Stack on NSTX will require modifications to the existing coolant system. This WBS element will provide water cooling services to the new Center Stack and ancillary equipment in the NSTX test cell.

{Water System Coolant Modifications for CSU (Job 3200)}

WBS Element: 1.3.3 **WBS Level: 3**

WBS Title: Bakeout Heating System

Definition: The bakeout heating system's function is to bake out the vacuum vessel and center stack in vacuum components at high temperature while keeping the outer vacuum vessel wall and ports within cooler design temperature limits. The system includes a pressurized hot water system to maintain the vessel wall temperature, a high pressure hot helium system to heat the in-vessel components, and a power supply for resistively heating the center stack walls. The controls and interlocks for safe operation of this system are included. This WBS element includes the engineering design, analysis, procurement activities and component fabrication.

This WBS element includes the purchase of a new more powerful power supply, to replace the existing one, to be used for electrical heating of the vessel. It is proposed to buy a 0-8V, 8000 amps for the application. Suitable cable leads will be fabricated and necessary interlocks

{NSTX CSU Bakeout System Mods (Job 3300)}

WBS Element: 1.3.4 **WBS Level: 3**

WBS Title: Gas Delivery Systems

Definition: The Gas Delivery Systems provides storage and delivery of gases to and from NSTX systems during experimental operations. These systems provide:

- Storage of on-site inventories of gases for use in NSTX plasma physics and future neutral beam experiments;
- Delivery of prescribed quantities of gases at prescribed purity levels and

flow rates;

- Delivery of gases continuously or in pulses of prescribed shape and duration; and
- Evacuation of delivery lines and components required for delivery.

This WBS includes engineering design, analysis, procurement activities, component fabrication and installation to the coil, bus and component cooling manifolds at the torus. The relocation of racks, control equipment and external delivery system is covered under WBS 1.2.4.9.

This WBS element includes the design, fabrication and installation, and test of up to four center stack fueling lines and modifications of the gas delivery assemblies.

{Gas delivery system modifications (Job 3400)}

WBS Element: 1.3.5 **WBS Level: 3**

WBS Title: Glow Discharge Cleaning System

Definition: The Glow Discharge Cleaning (GDC) System establishes and controls the GDC process in NSTX. GDC is a mode of vacuum conditioning in which the vacuum vessel internal surfaces are cleaned by the bombardment of ions formed during the glow process. This WBS includes engineering design, analysis, procurement activities, component fabrication and installation of the GDC system. The relocation of racks and control equipment is covered under WBS 1.2.4.9. There are no changes to the Glow Discharge Cleaning system as part of the NSTX Upgrade Project.

WBS Element: 1.4 **WBS Level: 2**

WBS Title: Plasma Diagnostics

Definition: The Plasma Diagnostics provide information on discharge parameters to characterize NSTX plasmas and guide its operation for optimized performance. The near term emphasis will be on detailed measurements of plasma profiles, using equipment presently available at PPPL. The long term objective will be to provide input for advanced plasma control systems, using new concepts and systems developed by the national NSTX team.

WBS Element: 1.4.1 **WBS Level: 3**

WBS Title: Plasma Diagnostics

Definition: The Plasma Diagnostics provide information on discharge parameters to characterize NSTX plasmas and guide its operation for optimized performance. The diagnostic subsystems included in this WBS are:

- Magnetic measurement diagnostics;
- Current density profile diagnostics;

- Laser and microwave diagnostics;
- Visible and total radiation diagnostics;
- Ultra violet and x-ray diagnostics;
- Particle measurement diagnostics;
- Divertor diagnostics; and
- Plasma Edge and vacuum diagnostics.

The NSTX Center Stack Upgrade will require new magnetic diagnostics to be installed This WBS element includes the design and fabrications of Center Stack magnetics diagnostics to replace units removed with the old Center Stack. Installation of these diagnostics is included in WBS element 1.1.3.3.4.

{Center Stack Upgrade Diagnostics (Job 4100)}

The increased diameter of the Center Stack Upgrade requires changes to the laser beam path, which requires a new laser input vessel penetration, and plugging of the existing penetration. Increasing the nozzle diameter of the L port to accommodate an external laser dump, furnishing a vacuum boundary for the extension tube. Modifications are to anticipate a third laser in the future and a new penetration for a FIDA diagnostic above and slightly offset from Bay L. The laser input location may require a special design of the PF coil support column between Bays F and G

Center Stack Diagnostic Job 4500

WBS Element: 1.5 **WBS Level: 2**

WBS Title: Power Systems

Definition: The Power Systems WBS element includes the engineering, design, prototyping, procurement and installation of all the systems and related elements that provide conditioned electrical power and energy to the NSTX systems. It includes the AC Power Systems, the AC/DC Convertors, the DC Systems, the Control and Protection System, and System Design and Integration as well as the coil bus runs..

WBS Element: 1.5.1 **WBS Level: 3**

WBS Title: AC Power Systems

Definition: The scope of the AC Power Systems WBS element is to provide the supply and distribution of all AC power to NSTX. This includes all the experimental and auxiliary loads.

AC/DC Converters

: The scope of the AC/DC Converters WBS element is to reactivate existing AC/DC Converters that have not been used since the shutdown of TFTR for use by NSTX.

DC Systems

The scope of the DC Systems WBS element is to receive AC input power and deliver controlled DC output power to the NSTX coil systems. This includes power cabling changes, DC Reactor changes, associated raceway changes, and changes required in the Power Cable Termination Structure (PCTS) inside the NSTX Test Cell.

Power Systems Integration and Testing

This WBS element covers general power systems activities including interaction with the designers of other WBS elements, design review support and procedure preparations as well as the administrative and supervisory efforts for the NSTX Power Systems.

{NSTX Center Stack Upgrade Power Systems (Job 5000)}

WBS Element: 1.5.2 **WBS Level: 3**

WBS Title: Control and Protection System

Definition: The scope of the Control and Protection System WBS element is to control and protect the power loop components for all magnet circuits. This includes the design of hardwired interlock system, kirk-keys, real time controls, the PC Link, Firing Generator, and Fault Detector changes, measurement of signals, changes to existing coil protection devices and design of a new digital coil *protection system. The Center stack upgrade entails the TF feed to be 1kV, 129.8kA for 7.45 seconds every 2400 seconds. Design shall be such that the pulse period can be reduced to 1200 seconds. This requires complete redesign of the TF power system. Replacement of the fault detector (FD) and the Firing* generator (FG) is required for fast and reliable response to fault conditions. The FD and FG are not included in the project work scope but part of the NSTX Program power supply reliability future upgrade. The HCS will be upgraded with a PLC. The OH power supply is designed to have the capability of 6kV, +/-24kA; OH CLRs will be replaced with calculated optimum requirements. A Digital Coil Protection (DCP) System will be designed and implemented. A Digital Coil Protection (DCP) System will be designed and implemented.

{NSTX Digital Coil Protection System (Job 5200)}

WBS Element: 1.5.3 **WBS Level: 3**

WBS Title: Coil Bus Runs

Definition: This WBS element includes the design and fabrication of the coil bus runs/supports between the NSTX coils and the FCPC cable terminations located in the NSTX test cell.

{Coil Bus Runs (Job 5501)}

WBS Element: 1.6 **WBS Level: 2**

WBS Title: Central Instrumentation and Controls (I&C)

Definition: This upgrade will be capable of producing plasmas on the order of 6.5 seconds; to-date they are less than two seconds. For dozens of CAMAC and PC-based data acquisition systems this will require an upgrade, and, in some cases, replacement. The real-time plasma control system will require an upgrade to accommodate additional input/output signals, control loops, and a longer control period. The networks and analysis pool computers will need to be upgraded to achieve reasonable performance for time-sensitive functions. Some test cell racks will be relocated; there will be a modest effort required to route the control, timing, and communication cabling and qualify the systems.

{Central I&C and Data Acquisition (Job 6100)}

WBS Element: 1.7 **WBS Level: 2**

WBS Title: Project Support & Integration

Definition: Project support and integration includes the non-hardware related subsystems such as overall Project Management and Administration, Project Physics as well as Integrated Systems Testing support.

WBS Element: 1.7.1 **WBS Level: 3**

WBS Title: Project Management and Integration

Definition: The project management and integration WBS element consists of all the activities necessary to plan, monitor, integrate and control, and report on the progress of the NSTX Upgrade Project which includes technical, business, and administrative planning and support; organizing, directing, coordinating, controlling, reviewing and approving project actions.

WBS Element: 1.7.1.1 **WBS Level: 4**

WBS Title: Project Management & Integration

This WBS element includes overall management; a Project Manager, Deputy Project Manager, and Project Controls support to manage, monitor, integrate, control, and report on the progress on the NSTX Upgrade. Also included in this WBS element is System Engineering support and support for updating of the General Arrangement Drawings for the NSTX Test Cell as well as funds for independent reviewers as necessary.

{Project Management and Integration (Job 7100)}

WBS Element: 1.7.1.2 **WBS Level: 4**

WBS Title: Center Stack Upgrade Management

Definition: Level of Effort job to cover the oversight of Center Stack Upgrade work which includes a Manager, Project Engineering support and support and to cover Center Stack engineer's time to prepare for and participate in project cost and schedule reviews.

{NSTX CSU Project Management (Job 7200)}

WBS Element: 1.7.1.3 **WBS Level: 4**

WBS Title: Neutral Beam Upgrade Management

Definition: Level of Effort job to cover the oversight of the 2nd Neutral Beam Upgrade work which includes a Manager, Engineering support and support and to cover Neutral Beam engineer's time to prepare for and participate in project cost and schedule reviews.

{NBI Project Support & Integration (Job 7300)}

WBS Element: 1.7.1.4 **WBS Level: 4**

WBS Title: Health Physics Support

Definition: This WBS element includes the effort necessary for continuous health physics (HP) support for the Neutral beamline decontamination, refurbishment, and relocation to the NTC as well as the HP support for equipment removal and relocations being accomplished under WBS 1.2.4.

{Health Physics Technical Support (Job 7400)}

WBS Element: 1.7.1.5 **WBS Level: 4**

WBS Title: Direct Allocations (Job 7710)

Definition: This WBS element includes the costs to cover Laboratory Engineering and Scientific Computing and Environmental Services that are allocated to all Laboratory projects based on their funding levels. Also included in this WBS element are the home office Health Physics efforts necessary to support the collection of radiological analyses of various environmental samples and bioassay samples, and the collection of analyses of data on the gamma radiation spectra of radioactive material at PPPL that are allocated to all Laboratory projects based on their usage of Health Physics staff.

{NSTX Upgrade Direct Allocations (Job 7710)}

WBS Element: 1.7.2 **WBS Level: 3**

WBS Title: Project Physics

Definition: Project Physics includes the definition of requirements necessary to meet the overall NSTX mission and supporting objectives, physics analysis supporting the project's design and construction activities, and definition of R&D needs. In addition it includes the provision of hardware and software required for plasma control.

Project Physics is not included in the scope of the Upgrade Project.

WBS Element: 1.7.3 **WBS Level: 3**

WBS Title: Integrated Systems Tests

Definition: This element includes all of the activities associated with the support of development of all necessary procedures and documents to support the integrated tests, and to support performance of the pre-operational integrated system tests culminating in first plasma.

The WBS element includes Convening the NSTX Activity Certification Committee (ACC) for comprehensive review the upgrades. Prepare and make presentation to the PPPL ES&H Executive Safety Board for issuance of appropriate Safety Certificate parameters for operation of NSTX with new enhanced operating capabilities; preparation of documentation (procedures) for safely integrating the upgrades for operations within NSTX safe operating parameters; working with NSTX Operations Group for the successful integration of the upgrades.

{Integrated Systems Test (Job 7900)}

WBS Element: 1.8 **WBS Level: 2**

WBS Title: Site Preparation and Assembly

Definition: Site preparation and torus assembly includes modifications to the existing NSTX Test Cell components and subsystems and the assembly and installation of all Torus Systems (WBS 1.1). Modifications to other PPPL facilities, components, and subsystems outside the NSTX Test Cell and the assembly and installation of non-torus components and subsystems are included in the individual components and subsystems.

WBS Element: 1.8.1 **WBS Level: 3**

WBS Title: Site Preparation

Definition: This WBS element includes construction of the NSTX machine platform and the modifications to the NSTX Test Cell. There are no activities in this WBS element as part of the NSTX Upgrade Project. NTC equipment removals, relocations and platform modifications necessary to support installation of the 2nd NBI are included in WBS element 1.2.4.2.

WBS Element: 1.8.2 **WBS Level: 3**

WBS Title: Torus Assembly and Construction

Definition: Torus Assembly and construction includes the assembly and installation of the NSTX torus, coils systems and all associated supports including construction management. This WBS element includes removal of equipment for clearance and accessibility, moving existing coils, modifying existing supports mounted on the vacuum vessel and installing a new external coil support structure.

{Installation of the Coil Support System (Job 8200 LOE tasks & 8210 discrete tasks)}

Also included in this WBS element is the removal of the existing Center Stack and installation of the NSTX Upgraded Center Stack, followed by closing up the vacuum vessel, pumping down, leak checking, bakeout and machine area scrubs to be ready for Integrated System Testing.

{CS Removal & Re-Installation/Pumpdown/Bakeout (Job 8250)}

Appendix B

Detailed Technical Performance Achieved

NSTXU Project Scope Completion Verification

In addition to satisfying the project KPP's identified in the Project Execution Plan (PEP), both PPPL and DOE agreed to a format for verifying that all scope called out in the Work Breakdown Structure (WBS as shown in the PEP) has been delivered.

The methodology that was adopted required each of the Control Account Managers (CAMs) to review their WBS dictionaries and verify that their project scope had been delivered at the control account level or indicate what work remained to be delivered and when it would be completed. In addition, the CAMs verified that the WBS Dictionary was accurate, or indicated what changes would be necessary to reconcile the dictionary and the scope of work delivered.

The forms, called Project Closeout Acknowledgement (PCA) forms, were filled out by the CAMs and countersigned by their responsible line manager (RLM). Each PCA was then reviewed and approved by the NSTXU project manager.

Review of this documentation as of _________ indicated that the project scope has been delivered.

_______________________________________ _____________

Ron Strykowsky, NSTXU Project Manager Date

_______________________________________ _____________

Mike Williams, Associate Director PPPL Date

_______________________________________ _____________

Stewart Prager, Laboratory Director PPPL Date

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-****-1000	Title: Center Stack Upgrade (CSU) analytical Support
WBS: 1.1.0	Control Account Manager (CAM): L. Dudek

Scope Description;

This WBS element includes development of a project integrated model and the associated analysis support of the overall NSTX Upgrade Project.

As a result of the NSTX Upgrade Project, the NSTX global models and analyses was updated. This WBS element included analytical support for global models and analysis not presently identified. The global model provides the basis for updating the analysis to qualify components and identify areas of the tokamak requiring further analysis. Identified plasma scenarios and power supply current limit analyses were run in the global model and current sets that required further analysis were identified. These analyses also serve to check the results of more detailed analyses.

Is all work scope for this control account complete per the control account plan?

■ Yes ☐ No (Describe when the work will be completed)

Does the WBS dictionary accurately represent the work completed?

■ Yes ☐ No (Describe additions and/or exclusions below)

Acknowledgement	Name	Signature	Date
Control Account Manager (CAM)	Larry Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.13 16:16:15 -04'00'	
Responsible Line Manager (RLM)	Larry Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.13 16:16:32 -04'00'	
Project Manager	Ron Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 07:33:43 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1001**	**Title: {Center Stack Upgrade (CSU) PFCs**
WBS: 1.1.1	**Control Account Manager (CAM): K.Tresemer**

Scope Description;

The plasma facing components (PFCs) include all the systems and related elements that serve to protect the vacuum vessel from the charged particles and radiation flux from the plasma. These include the plasma facing tiles and mounting components, passive stabilizers, inner wall protection, divertor area strike plates, and local I&C. This element consists of the engineering design, analysis, procurement activities and component fabrication.

The NSTX Upgrade Project required new PFCs on the new Center Stack Casing (CSC) and the new Inboard divertor (IBD). This WBS element includes the design and analysis for both the CS and IBD PFCs, design modifications to the PFC tiles to accommodate surface diagnostics, including design of the tile mounting schemes and routing plans for diagnostic wires, generation of required documentation such as checked calculations, specifications and procedures, the procurement and installation of all PFC tiles and hardware on the CSC and IBD.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☐ **Yes** ■ **No (Describe additions and/or exclusions below)**

Additional scope covering the upgrade and installation of the Row 1 Outboard Divertor Tiles was added in response to analyses which suggested that it was possible to run plasma scenarios where the strike point hit the side of the PF1C canister, a vacuum barrier. The subsequent design changes to both the Inboard and Outboard Row 1 tiles were needed to provide thermal shadowing of this affected zone. This work was completed along with the rest of the 1001 WBS scope.

Acknowledgement	Name	Signature	Date
Control Account Manager (CAM)	Kelsey Tresemer	Kelsey Tresemer Digitally signed by Kelsey Tresemer DN: cn= Kelsey Tresemer, o=PPPL, ou=Engineering, email=ktreseme@pppl.gov, c=US Date: 2015.04.13 14:30:54 -04'00'	
Responsible Line Manager (RLM)	Larry Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.13 16:13:28 -04'00'	
Project Manager	Ron Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou= PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 07:34:31 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1002**	**Title: Passive Plate Analysis and Upgrade Activity**
WBS: 1.1.1	**Control Account Manager (CAM):** N.Atnafu

Scope Description;

The NSTX Upgrade required analysis of the passive plates for disruption and thermal loads. CDR level calculations were performed that addressed one of five disruptions. The remaining identified disruptions were completed during Preliminary & Final Design. Modest hardware upgrades are anticipated as part of this task. Additions of accelerometers or other diagnostics to benchmark calculations with actual performance in NSTX were provided. This analysis effort is included in this WBS element.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgement	Name	Signature	Date
Control Account Manager (CAM)	Neway Atnafu	Neway Atnafu Digitally signed by Neway Atnafu DN: cn= Neway Atnafu, o=Princeton Plasma Physics Lab, ou= PPPL, email=natnafu@pppl.gov, c=US Date: 2015.04.15 09:01:06 -04'00'	
Responsible Line Manager (RLM)	Larry Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.17 09:35:01 -04'00'	
Project Manager	Ron Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn= Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.21 09:03:41 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-1200**	**Title: Vacuum Vessel & Support Structure**
WBS: 1.1.2	**Control Account Manager (CAM):** M. Smith

Scope Description;

The vacuum vessel & support structure (VVSS) consists of the vacuum chamber, not including the PFCs, all ports and vacuum boundary closures and the torus support structure which provides the overall supporting mechanism for the torus components to the test cell floor. This WBS element includes the engineering design, analysis, procurement activities and component fabrication.

The NSTX Upgrade Project required that the existing VVSS be modified to accommodate the new center stack structure, including the umbrella structure and the new center stack support structure. This WBS element includes the analytical and CAD design of the support structures associated with the Magnet upgrade activities. The scope includes; the Vacuum Vessel & Structural Support, the Outer TF Structures, the Outer PF Coil Structures, the Umbrella Structural Reinforcement, the CS Support Pedestal and miscellaneous Vacuum Vessel Structural Supports. It also includes the procurement and fabrication of these structures, but does not include installation costs. Installations costs are included in WBS 1.8 CA 8200.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Note: generally speaking, the description above is correct. However, structure / upgrades needed to the VV due to the 2nd neutral beam was not within the scope of CA 1200 but included in WBS 1.2 CA 2480. Also, structure / upgrades to the VV and/or diagnostic ports due to specific diagnostics was not within the scope of CA 1200 but included in WBS 1.4 CA 4500.

Acknowledgement	Name	Signature	Date
Control Account Manager (CAM)	Mark Smith	Mark Smith — Digitally signed by Mark Smith DN: cn=Mark Smith, o=PPPL, ou, email=msmith@pppl.gov, c=US Date: 2015.04.21 10:06:35 -04'00'	
Responsible Line Manager (RLM)	Larry Dudek	[signature] Digitally signed by Lawrence E. Dudek Date: 2015.04.21 10:26:35 -04'00'	
Project Manager	Ron Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.21 10:34:14 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-****-1300 & 1310	Title: Upgrade Project Design Support (Job 1300)
WBS: 1.1.3	Control Account Manager (CAM): S. Raftopoulos

Scope Description;

This WBS element provided CAD design support and engineering supervision for the overall assembly associated with the CSA upgrade. It also included time for space allocation studies associated with the magnet upgrades. CAD design support for individual components is included in the specific component jobs.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S. Raftopoulos	Steve Raftopoulos Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:53:46 -04'00'	
Responsible Line Manager (RLM)	L. Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:25:22 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 08:51:20 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1301**	**Title: Outer Toroidal Field Coil Repairs (Job 1301)**
WBS: 1.1.3.2	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

The outer Toroidal Field coils subsystem consists of the coil sections that make up the 12 TF outer legs. This WBS element included the design, analysis, prototypes (as required), procurement activities and fabrication. This WBS element included the fabrication of (2) new Outer TF coils to replace the existing leaking OTF#7 and OTF#11 that were removed during the Neutral Beam port upgrade. These coils will then be used as a spare for future operations in NSTX. The scope included the procurement of conductor, insulation material, aluminum castings and supports necessary to fabricate a new OTF coils. Coil fabrication was performed by an outside vendor. This scope does not include costs associated with installation. Installations costs are included in WBS 1.8

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	**S. Raftopoulos**	Steve Raftopoulos — Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:54:07 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:25:09 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 08:52:08 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1302**	**Title:** Center Stack Assembly (Job 1302)
WBS:1.1.3.3.4	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

The Center Stack Assembly effort involved the activities associated with the assembly of the Center Stack and included design modifications and upgrade of the coil assembly stand; procedures for assembling the Center Stack and for installation; assembly of the Center Stack components including the OH/TF coil supports, mounting of the OH Solenoid surface diagnostics and thermal blanket, inconel casing and inner PF coils and setup and tear down of the Center Stack assembly area.

Is all work scope for this control account complete per the control account plan?

☒ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☒ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S.Raftopoulos	Steve Raftopoulos — Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:54:28 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:24:52 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 08:52:46 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1303**	**Title:** TF Joint Stand & Performance Test (Job 1303
WBS:1.1.3.3.1	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

For the NSTX Upgrade Project a test stand to measure the required performance parameters on the new NSTX TF joint design was designed and fabricated. Test parameter measurements and cyclic lifetime tests of the new TF joint materials were performed and testing data was compiled. Results were used for the design of centerstack components.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S.Raftopoulos	Steve Raftopoulos Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:54:51 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:24:39 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 09:00:12 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1304**	**Title:** Inner Toroidal Field Bundle (Job 1304)
WBS: 1.1.3.3.1	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

For the NSTX Upgrade Project a new TF Inner Leg was fabricated. This WBS element includes the design of the TF Bundle, the TF flex bus and flex bus supports and included all analytical and CAD design efforts for these components. It also included the procurement of the TF conductor [80 lengths] and procurement of the TF flex bus and supports. It does not include the procurement/fabrication of the OH, which is included as part of the OH procurement in WBS 1.1.3.3.2.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S.Raftopoulos	Steve Raftopoulos — Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:55:11 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:24:14 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 09:00:59 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-1305**	**Title:** Ohmic Heating Solenoid (Job 1305)
WBS: 1.1.3.3.2	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

For the NSTX Upgrade a new OH Solenoid was fabricated. This WBS element included the design & fabrication of a new OH solenoid and associated components including a Belleville washer spring assembly and support structures for the NSTX upgrades. It also included all analytical & CAD design efforts. Includes advance procurement of the copper conductor and co-wound [glass/Kapton] insulation. Also includes the procurement of the Micro-therm insulation, conductive paint.

Includes the in-house fabrication for the combined OH and TF bundle assembly.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S.Raftopoulos	Steve Raftopoulos Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:55:36 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:24:00 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 09:01:32 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-1306**	**Title:** Inner Poloidal Field Coils (Job 1306)
WBS: 1.1.3.3.3	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

The inner poloidal/shaping coils subsystem consists of the new coils that will make up the poloidal field coils 1A, 1B and 1C. This WBS element includes the design, analysis, procurement activities and fabrication.

For the NSTX Upgrade three new sets of inner poloidal field coils were fabricated and installed. This WBS element includes the design and procurement of the Inner poloidal field coils and supports which includes all analytical and CAD design efforts for these components. It includes the early procurement of the PF conductor and co-wound [Glass/Kapton] insulation.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S.Raftopoulos	Steve Raftopoulos — Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:55:53 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:22:12 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 09:02:04 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-1307**	**Title:** CS Casing (Job 1307)
WBS: 1.1.3.3.4	**Control Account Manager (CAM):** S. Raftopoulos

Scope Description;

This WBS element includes the design and fabrication of the Center Stack casing and ceramic break assembly for the upgraded Center Stack as well as the assembly of the new Center Stack. The Center Stack Casing effort includes analysis and CAD design for the casing components; the procurement of the Inconel tubing, forgings, bellows and organ pipes; the fabrication of Center Stack support legs; the procurement/fabrication of a new ceramic break assembly; the in-house assembly of the casing components; and mounting of the PF1A and PF1B structure/coils to the casing.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S.Raftopoulos	Steve Raftopoulos Digitally signed by Steve Raftopoulos DN: cn=Steve Raftopoulos, o=Princeton Plasma Physics Laboratory, ou=Engineering, email=sraftopo@pppl.gov, c=US Date: 2015.04.13 16:56:18 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.14 08:21:54 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.14 09:02:36 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9418-**-2300**	**Title:** Electron Cyclotron Heating (Job 2300)
WBS: 1.2.3	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

This scope of the WBS element for the NSTX Upgrade covers the ECH and other antenna systems, and miscellaneous diagnostics and components attached to the vessel which will be affected by the increases in EM and thermal loading. Disruption loads on the ECH waveguide were evaluated for the Center Stack Upgrade Fields and field transients. Only disruption qualification calculations were performed.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T. Stevenson	[signature]	3/19/15
Responsible Line Manager (RLM)	T.Stevenson	[signature]	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9418-**-2420**	**Title:** 2nd NBI Source Refurbishment (Job 2420)
WBS: 1.2.4.2	**Control Account Manager (CAM): M.Cropper**

Scope Description;

This WBS element included the activities to refurbish three neutral beam ion sources for the 2nd Neutral beamline, as currently being performed for the installed Neutral beamline 1.

Is all work scope for this control account complete per the control account plan?

X Yes ☐ No (Describe when the work will be completed)

Due to TF fault 7/20/2011, existing sources were available so no new sources needed refurbishment.

Does the WBS dictionary accurately represent the work completed?

X Yes ☐ No (Describe additions and/or exclusions below)

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	M.Cropper	Mark B. Cropper — Digitally signed by Mark B. Cropper DN: cn=Mark B. Cropper, o=Princeton Plasma Physics Lab, ou=Neutral Beam, email=mcropper@pppl.gov, c=US Date: 2015.07.23 12:09:28 -04'00'	
Responsible Line Manager (RLM)	T.Stevenson	Timothy N. Stevenson — Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.07.23 16:02:02 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.27 12:50:13 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9418-**-2425**	**Title:** NSTX Beamline 2 Relocation (Job 2425)
WBS: 1.2.4.4	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

Also included in WBS element 1.2.4.4 are the efforts necessary to relocate a TFTR neutral beam line and ancillary equipment into the NSTX test cell. This includes High Voltage Enclosures (HVEs) and the complete beam box and components.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	T.Stevenson	T. Stevenson	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9418-**-2430**	**Title:** NSTX Beamline 2 Decontamination (Job 2430)
WBS:1.2.4.3	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

This WBS element included the disassembly and decontamination of a TFTR Neutral Beam beamline in preparation for beamline refurbishment and reuse as an NSTX upgrade.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	T.Stevenson	T. Stevenson	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9418-**-2440**	**Title:** NSTX Beamline 2 Refurbishment & Relocation(Job 2440)
WBS: 1.2.4.4	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

This WBS element included refurbishment of a TFTR NBI and its relocation to the NSTX test cell.

Included in this WBS element are the activities necessary to refurbish a TFTR Neutral Beam beamline for use on NSTX. This scope included replacing the ion dump and calorimeter bellows and refurbishment of the seals, thermocouple wiring, and bellows (cal and spool).

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	**Name**	**Signature**	**Date**
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	T.Stevenson	T. Stevenson	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project

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Control Account: 9418-**-2450**	**Title:** NSTX Beamline 2 Services (Job 2450)
WBS: 1.2.4.5	**Control Account Manager (CAM): M.Cropper**

Scope Description;

This WBS element included the efforts to provide services to the new neutral beam beamline and ancillary equipment in NSTX test cell. These services include water, cryogenic systems, gas supplies, and vacuum lines.

Is all work scope for this control account complete per the control account plan?

X Yes ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

X Yes ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	M.Cropper	Mark B. Cropper Digitally signed by Mark B. Cropper DN: cn=Mark B. Cropper, o=Princeton Plasma Physics Lab, ou=Neutral Beam, email=mcropper@pppl.gov, c=US Date: 2015.07.23 12:11:16 -04'00'	
Responsible Line Manager (RLM)	T.Stevenson	Timothy N. Stevenson Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.07.23 16:03:52 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.27 12:50:44 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9418-**-2460**	**Title:** NBI Armor (Job 2460)
WBS: 1.2.4.6	**Control Account Manager (CAM):** K. Tresemer

Scope Description;

This WBS element included the design, fabrication, and installation of upgraded and relocated neutral beam armor including cooling and instrumentation work.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	K.Tresemer	Kelsey Tresemer — Digitally signed by Kelsey Tresemer DN: cn=Kelsey Tresemer, o=PPPL, ou=Engineering, email=ktreseme@pppl.gov, c=US Date: 2015.04.21 12:14:28 -04'00'	
Responsible Line Manager (RLM)	T.Stevenson	Timothy N. Stevenson — Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.04.21 16:12:28 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.05 13:41:01 -04'00'	

NSTX Upgrade Project
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Control Account: 9418-**-2470**	**Title:** NBI Power System (Job 2470)
WBS: 1.2.4.7	**Control Account Manager (CAM):** S. Ramakrishnan

Scope Description;

Included in this WBS element is providing power for the NBI beamline 2. NB2 is planned is powered from the TFTR NB4 A, B, & C line ups. The electrical equipment in these line ups was reactivated. The TFTR NB4 HVEs were relocated to the NSTX Test Cell as part of WBS element 1.2.4.4. New triax cables were installed with terminations from the Modregs to the HVEs. New Decel coaxial cables were installed from the Decel supplies to the Sources. The Arc, Filament, Magnet, and the 208 feeds, to HVEs cables, were spliced in the TFTR Test Cell basement to new cabling designed and installed from the TFTR Basement to the NSTX Test Cell. The fiber cables also were spliced with additional lengths recovered from other TFTR line ups. The AC auxiliaries and Grounding for the NB2 were designed and installed.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	S. Ramakrishnan	S. Ramakrishnan Digitally signed by S. Ramakrishnan DN: cn=S. Ramakrishnan, o=PPPL, ou=Engineering, email=raki@pppl.gov, c=US Date: 2015.04.22 12:29:47 -04'00'	04/12/15
Responsible Line Manager (RLM)	T.Stevenson	Timothy N. Stevenson Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.04.22 15:26:24 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.05 13:43:41 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9418-**-2475**	**Title:** NBI Controls & Instrumentation (Job 2475)
WBS:1.2.4.7	**Control Account Manager (CAM):** M. Cropper

Scope Description;

Also included in WBS element 1.2.4.7 are the controls and instrumentation for the NB2. The work covers PLC, programming, control racks, new thermocouples, TC scanner, miscellaneous controls, and control cabling. The work also includes the gradient grid upgrade. System integration and testing will also be performed as part of this effort.

Is all work scope for this control account complete per the control account plan?

■ Yes ☐ No (Describe when the work will be completed)

Does the WBS dictionary accurately represent the work completed?

■ Yes ☐ No (Describe additions and/or exclusions below)

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	M.Cropper	Mark B. Cropper Digitally signed by Mark B. Cropper DN: cn=Mark B. Cropper, o=Princeton Plasma Physics Lab, ou=Neutral Beam, email=mcropper@pppl.gov, c=US Date: 2015.05.12 07:10:37 -04'00'	
Responsible Line Manager (RLM)	T.Stevenson	Timothy N. Stevenson Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.05.12 09:31:30 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.05.12 10:34:06 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
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Control Account: 9418-**-2480**	**Title:** NSTX NB2 Duct & VV Mods (Job 2480)
WBS: 1.2.4.8	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

This WBS element included the design, and fabrication of all components connecting the Neutral Beam Box to NSTX, and the connecting ductwork and modifications to NSTX Vacuum Vessel to accommodate the second beamline.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	T.Stevenson	T. Stevenson	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project
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Control Account: 9418-**-2485**	**Title:** NSTX NB2 TVPS (Job 2485)
WBS:1.2.4.0	**Control Account Manager (CAM):** W. Blanchard

Scope Description;

In order to accommodate the installation of the 2nd NBI on NSTX the Vacuum Pumping System was modified. This WBS element included the design, fabrication, and installation of a new vessel pumping system and includes new pump ducts off of the Neutral Beamline 2 duct, mechanical and electrical isolation of the system, vacuum diagnostic relocation, magnetic.

This WBS element also includes the controllers for all pumps. The relocation of racks and control equipment is covered under WBS 1.2.4.9

Is all work scope for this control account complete per the control account plan?

☒ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☒ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	**W.Blanchard**	W. Blanchard — Digitally signed by W. Blanchard DN: cn=W. Blanchard, o=PPPL, ou=Engineering, email=wblancha@pppl.gov, c=US Date: 2015.03.24 13:58:34 -04'00'	
Responsible Line Manager (RLM)	T. Stevenson	Timothy N. Stevenson — Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.04.22 09:23:37 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.05 13:48:46 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9418-**-2490**	**Title:** NTC Equipment Removals/Relocations (Job 2490
WBS: 1.2.4.9	**Control Account Manager (CAM):** E. Perry

Scope Description;

This WBS element covers moving of racks and diagnostics to clear space in the NSTX Test Cell (NTC) for the second Neutral Beamline. Racks to be removed and re-installed in a new location are #419, 431-435, 440-445, 447-449, 488. Racks 456 and 489 will be removed and excess. This scope also includes the fabrication and installation of five sections of platform at elevation 118' on the west side of the NTC to accommodate the racks being re-installed in the NTC. Racks #441-445 will be relocated to the Gallery east of the NTC. Diagnostics to be removed are those from the midplanes of Bay J and Bay K as well as those on the present pump duct. The diagnostics from Bay J will be re-installed ~5" outboard of their present position. IR windows and the Transmission Grating Spectrometer will be relocated to the new NB duct. Ion gages, filaments and the RGA will be relocated to the new pump duct under the NB2 duct. SPRED and LOWEUS will be relocated to Bay L. The Thomson Scattering Beam Dump Window will be relocated to between Bays K and L.

Is all work scope for this control account complete per the control account plan?

☐ **Yes** ■ **No (Describe when the work will be completed)**

SPRED and LOWEUS re-installation deleted from scope.

Does the WBS dictionary accurately represent the work completed?

☐ **Yes** ■ **No (Describe additions and/or exclusions below)**

SPRED and LOWEUS re-installation deleted from scope.

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	E.Perry	Erik D. Perry — Digitally signed by Erik D. Perry DN: cn=Erik D. Perry, o, ou, email=eperry@pppl.gov, c=US Date: 2015.05.06 10:13:12 -04'00'	
Responsible Line Manager (RLM)	T. Stevenson	Timothy N. Stevenson — Digitally signed by Timothy N. Stevenson DN: cn=Timothy N. Stevenson, o=PPPL, ou=ENGR, email=tstevenson@pppl.gov, c=US Date: 2015.07.22 16:12:01 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:17:13 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-****-3200	**Title:** Water System Coolant Modifications for CSU (Job 3200)
WBS: 1.3.2	**Control Account Manager (CAM):** N. Atnafu

Scope Description;

The Coolant System provides cooling water to remove heat generated from NSTX systems during experimental operations. The systems include the:

- **TF/PF bus and coil cooling water system;**
- **Center stack cooling water system;**
- **Component cooling water system; and the**
- **Ohmic heating cooling water system.**

These systems will provide cooling water for normal operations and discharge cleaning of the vacuum vessel. This WBS includes engineering design, analysis, procurement activities, component fabrication and installation to the coil, bus and component cooling manifolds at the torus.
The new Center Stack on NSTX required modifications to the existing coolant system. This WBS element provides water cooling services to the new Center Stack and ancillary equipment in the NSTX test cell.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	N. Atnafu	Neway Atnafu — Digitally signed by Neway Atnafu DN: cn=Neway Atnafu, o=Princeton Plasma Physics Lab, ou=PPPL, email=natnafu@pppl.gov, c=US Date: 2015.04.15 09:03:19 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.17 09:34:33 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.21 09:04:20 -04'00'	

NSTX Upgrade Project

Project Closeout Acknowledgement

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Control Account: 9417-**-3300**	**Title:** NSTX CSU Bakeout System Mods (Job 3300
WBS: 1.3.3	**Control Account Manager (CAM): S. Ramakrishnan**

Scope Description;

This WBS element includes the purchase of a new power supply/supplies, to replace the existing one, to be used for electrical heating of the vessel. It is proposed to buy two 0-8V, 0-4000 amps supplies for the application. The supplies will then be connected in parallel to get 0-8000A. Suitable cable leads will be fabricated and necessary interlocks will be incorporated.

Is all work scope for this control account complete per the control account plan?

X Yes ☐ No (Describe when the work will be completed)

Does the WBS dictionary accurately represent the work completed?

☐ Yes ☐ No (Describe additions and/or exclusions below)

The description can be amended as stated in the Scope

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	**S. Ramakrishnan**	S. Ramakrishnan Digitally signed by S. Ramakrishnan DN: cn=S. Ramakrishnan, o=PPPL, ou=Engineering, email=raki@pppl.gov, c=US Date: 2015.07.24 11:09:49 -04'00'	07/24/15
Responsible Line Manager (RLM)	L.Dudek	[signature]	Digitally signed by Lawrence E. Dudek Date: 2015.07.28 16:07:05 -04'00'
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.29 08:11:34 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
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Control Account: 9417-**-3400**	**Title:** Gas delivery system modifications (Job 3400)
WBS: 1.3.4	**Control Account Manager (CAM): W.Blanchard**

Scope Description;

This WBS included engineering design, analysis, procurement activities, component fabrication, installation and test of up to four center stack fueling lines and modifications of the gas delivery assemblies. The relocation of racks, control equipment and external delivery system is covered under WBS 1.2.4.9.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	W.Blanchard	W. Blanchard Digitally signed by W. Blanchard DN: cn=W. Blanchard, o=PPPL, ou=Engineering, email=wblancha@pppl.gov, c=US Date: 2015.07.27 11:22:48 -04'00'	
Responsible Line Manager (RLM)	LDudek	[signature]	Digitally signed by Lawrence E. Dudek Date: 2015.07.28 16:05:50 -04'00'
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.29 08:12:29 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
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Control Account: 9417-**-4100**	**Title:** Stack Upgrade Diagnostics (Job 4100)
WBS: 1.4.1	**Control Account Manager (CAM):** R. Kaita

Scope Description;

The Plasma Diagnostics provide information on discharge parameters to characterize NSTX plasmas and guide its operation for optimized performance. The diagnostic subsystems included in this WBS are; Magnetic measurement diagnostics, Current density profile diagnostics, Laser and microwave diagnostics, Visible and total radiation diagnostics, Ultra violet and x-ray diagnostics, Particle measurement diagnostics, Divertor diagnostics, and Plasma Edge and vacuum diagnostics.

The NSTX Center Stack Upgrade required new magnetic diagnostics that were installed. This WBS element included the design and fabrication of Center Stack magnetic diagnostics which replaced units removed with the old Center Stack. Installation of these diagnostics is included in WBS element 1.1.3.3.4.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	R.Kaita	Robert Kaita Digitally signed by Robert Kaita cn=Robert Kaita, o=Princeton Plasma Physics Laboratory, o=Princeton University, l=Princeton, st=New Jersey, c=US, email=kaita@pppl.gov Date: 2015.04.01 17:15:34 EDT	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.02 10:19:29 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.02 10:22:24-04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
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Control Account: 9417-**-4500**	**Title:** MPTS VV Modification Job 4500
WBS: 1.4.1	**Control Account Manager (CAM):** G. Labik

Scope Description;

The increased diameter of the Center Stack Upgrade required changes to the MPTS laser beam path, which required a new laser input vessel penetration, and plugging of the existing penetration, increasing the nozzle diameter of the L port to accommodate an external laser dump, furnishing a vacuum boundary for the extension tube. Modifications were made are to anticipate a third laser in the future and a new penetration for a FIDA diagnostic above and slightly offset from Bay L. The laser input location required a special design of the PF coil support column between Bays F and G.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☐ **Yes** ■ **No (Describe additions and/or exclusions below)**

The work scope expanded to include installing additional diagnostic vacuum interfaces :

1. Two ports for IR cameras to view the NB carbon tiles and the RF antennas.
2. Background CHERS and Future tangential views.
3. High K Scattering.
4. Fusion Products Probe.
5. FIReTIP or other Tangential View.
6. 6 Wire vacuum feedthroughs for magnetics inside the vacuum vessel.

7. Rerouted the RWM coils for Bays JK and AL
8. Funded the impact of multi physics loading of vacuum vessel to design the Bay L upgrade using a combination of Ansys and Maxwell software. The combined software was used to design other vessel changes and additions .

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	G.Labik	George Labik — Digitally signed by George Labik DN: cn=George Labik, o, ou, email=glabik@pppl.gov, c=US Date: 2015.03.18 08:29:44 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.16 09:30:11 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.16 09:43:53 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
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Control Account: 9417-**-5000**	**Title:** NSTX Center Stack Upgrade Power Systems (Job 5000)
WBS: 1.5.1	**Control Account Manager (CAM):** S. Ramakrishnan

Scope Description;

AC Power Systems: The scope of the AC Power Systems was to provide the supply and distribution of all AC power to NSTX. This included all the experimental and auxiliary loads.

AC/DC Converters: The scope of the AC/DC Converters was to reactivate existing AC/DC Converters that have not been used since the shutdown of TFTR for use by NSTX.

DC Systems: The scope of the DC was to receive AC input power and deliver controlled DC output power to the NSTX coil systems. This included power cabling changes, DC Reactor changes, associated raceway changes, and changes required in the Power Cable Termination Structure (PCTS) inside the NSTX Test Cell.

Power Systems Integration and Testing: This WBS element covers general power systems activities including interaction with the designers of other WBS elements, design review support and procedure preparations as well as the administrative and supervisory efforts for the NSTX Power Systems.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	**S. Ramakrishnan**	S. Ramakrishnan — Digitally signed by S. Ramakrishnan DN: cn=S. Ramakrishnan, o=PPPL, ou=Engineering, email=raki@pppl.gov, c=US Date: 2015.04.22 12:31:37 -04'00'	04/10/15
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.22 13:34:11 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:12:01 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-5200**	**Title:** NSTX Digital Coil Protection System (Job 5200)
WBS: 1.5.2	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

The scope of the Control and Protection System WBS element is to control and protect the power loop components for all magnet circuits. This includes the design of hardwired interlock system, kirk-keys, real time controls, the PC Link, Firing Generator, and Fault Detector changes, measurement of signals, changes to existing coil protection devices.

The scope of this job was to design, install, and test a new digital coil protection system (DCPS) on NSTXU.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	T.Stevenson	T. Stevenson	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-5501**	**Title:** Coil Bus Runs (Job 5501)
WBS: 1.5.3	**Control Account Manager (CAM):** N. Atnafu

Scope Description;

This WBS element included the design and fabrication of the coil bus runs/supports between the NSTX coils and the FCPC cable terminations located in the NSTX test cell.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	N.Atnafu	Neway Atnafu — Digitally signed by Neway Atnafu DN: cn= Neway Atnafu, o=Princeton Plasma Physics Lab, ou= PPPL, email=natnafu@pppl.gov, c=US Date: 2015.04.15 09:04:44 -04'00'	
Responsible Line Manager (RLM)	L.Dudek	Digitally signed by Lawrence E. Dudek Date: 2015.04.17 09:33:41 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn= Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.04.21 09:04:54 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-6100**	**Title:** Central I&C and Data Acquisition (Job 6100)
WBS: 1.6	**Control Account Manager (CAM): P.Sichta**

Scope Description;

This upgrade will be capable of producing plasmas on the order of 6.5 seconds; to-date they are less than two seconds. For dozens of CAMAC and PC-based data acquisition systems this will require an upgrade, and, in some cases, replacement. The real-time plasma control system was upgraded to accommodate additional input/output signals, control loops, and a longer control period. The networks and analysis pool computers were upgraded to achieve reasonable performance for time-sensitive functions. Some test cell racks were relocated; there was a modest effort required to route the control, timing, and communication cabling and qualify the systems.

Is all work scope for this control account complete per the control account plan?

× Yes ☐ No (Describe when the work will be completed)

Does the WBS dictionary accurately represent the work completed?

× Yes ☐ No (Describe additions and/or exclusions below)

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	P.Sichta	Paul Sichta — Digitally signed by Paul Sichta	
Responsible Line Manager (RLM)	L. Dudek		Digitally signed by Lawrence E. Dudek Date: 2015.07.28 07:33:27 -04'00'
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.28 07:46:18 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-7100**	**Title:** Project Management and Integration (Job 7100)
WBS:1.7.1.1	**Control Account Manager (CAM): R.Strykowsky**

Scope Description;

This WBS element includes overall management; a Project Manager, Deputy Project Manager, and Project Controls support to manage, monitor, integrate, control, and report on the progress on the NSTX Upgrade. Also included in this WBS element is System Engineering support and support for updating of the General Arrangement Drawings for the NSTX Test Cell as well as funds for independent reviewers as necessary.

Is all work scope for this control account complete per the control account plan?

☐ **Yes** ☑ **No (Describe when the work will be completed)**

Scope will be concluded upon;

1. Reconciliation of CD4 closeout review recommendations
2. Delivery of the final project closeout report
3. Final year end accounting adjustment verifications. Expected finish Sept 2015

Does the WBS dictionary accurately represent the work completed?

☑**Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	R.Strykowsky		
Responsible Line Manager (RLM)	Mike Williams		
Project Manager	M. Williams		

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-7200**	**Title:** NSTX CSU Project Management (Job 7200)
WBS: 1.7.1.2	**Control Account Manager (CAM): L.Dudek**

Scope Description;

Level of Effort job to cover the oversight of Center Stack Upgrade work which includes a Manager, Project Engineering support and support and to cover Center Stack engineer's time to prepare for and participate in project cost and schedule reviews.

Is all work scope for this control account complete per the control account plan?

☐ **Yes** ☑ **No (Describe when the work will be completed)**

Scope will be concluded upon;

4. Reconciliation of CD4 closeout review recommendations
5. Delivery of the preliminary project closeout report

Does the WBS dictionary accurately represent the work completed?

☐ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	L.Dudek		
Responsible Line Manager (RLM)	R.Strykowsky		
Project Manager	R.Strykowsky		

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9418-**-7300**	**Title:** NBI Project Support & Integration (Job 7300)
WBS: 1.7.1.3	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

Level of Effort job to cover the oversight of the 2nd Neutral Beam Upgrade work which includes a Manager, Engineering support and support and to cover Neutral Beam engineer's time to prepare for and participate in project cost and schedule reviews.

Is all work scope for this control account complete per the control account plan?

☐ **Yes** ☑ **No (Describe when the work will be completed)**

Scope will be concluded upon;

1. Reconciliation of CD4 closeout review recommendations
2. Delivery of the preliminary project closeout report.

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	R.Strykowsky	[signature]	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9418-**-7400**	**Title:** Health Physics Technical Support (Job 7400)
WBS: 1.7.1.4	**Control Account Manager (CAM):** T. Stevenson

Scope Description;

This WBS element includes the effort necessary for continuous health physics (HP) support for the Neutral beamline decontamination, refurbishment, and relocation to the NTC as well as the HP support for equipment removal and relocations being accomplished under WBS 1.2.4.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	T.Stevenson	T. Stevenson	3/19/15
Responsible Line Manager (RLM)	R.Strykowsky	T. Stevenson	3/19/15
Project Manager	R.Strykowsky	[signature]	3/19/15

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-7710**	**Title:** NSTX Upgrade Direct Allocations (Job 7710)
WBS: 1.7.1.5	**Control Account Manager (CAM): R.Strykowsky**

Scope Description;

This WBS element is a LOE overhead that includes the costs to cover Laboratory Engineering and Scientific Computing and Environmental Services that are allocated to all Laboratory projects based on their funding levels. Also included in this WBS element are the home office Health Physics efforts necessary to support the collection of radiological analyses of various environmental samples and bioassay samples, and the collection of analyses of data on the gamma radiation spectra of radioactive material at PPPL that are allocated to all Laboratory projects based on their usage of Health Physics staff.

Is all work scope for this control account complete per the control account plan?

☑ Yes ☐No (Describe when the work will be completed)

6. Work scope complete but final adjusted cost not available until end of fiscal year.

Does the WBS dictionary accurately represent the work completed?

☑ Yes ☐ No (Describe additions and/or exclusions below)

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	R.Strykowsky		
Responsible Line Manager (RLM)	R.Strykowsky		
Project Manager	M. Williams		

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-7900**	**Title:** Integrated Systems Test (Job 7900)
WBS: 1.7.3	**Control Account Manager (CAM): C.Gentile**

Scope Description;

The WBS element includes Convening the NSTX Activity Certification Committee (ACC) for comprehensive review the upgrades. Prepare and make presentation to the PPPL ES&H Executive Safety Board for issuance of appropriate Safety Certificate parameters for operation of NSTX with new enhanced operating capabilities; preparation of documentation (procedures) for safely integrating the upgrades for operations within NSTX safe operating parameters; working with NSTX Operations Group for the successful integration of the upgrades.

Is all work scope for this control account complete per the control account plan?

☑ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

☑ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	C.Gentile	Charles A. Gentile Digitally signed by Charles A. Gentile DN: cn=Charles A. Gentile, o, ou, email=cgentile@pppl.gov, c=US Date: 2015.08.11 13:48:44 -04'00'	
Responsible Line Manager (RLM)	A.vonHalle	Alfred von Halle Digitally signed by Alfred von Halle DN: cn=Alfred von Halle, o, ou, email=avonhalle@pppl.gov, c=US Date: 2015.08.11 13:03:03 -05'00'	
Project Manager	R.Strykowsky	Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.12 08:14:07 -04'00'	

NSTX Upgrade Project
Project Closeout Acknowledgement
CD-4

Control Account: 9417-**-8200**	**Title:** Installation of the Coil Support System (Job 8200 TASKS)
WBS: 1.8.2	**Control Account Manager (CAM):** E. Perry

Scope Description;

Torus Assembly and construction. Includes the assembly and installation of the NSTX torus, coils systems and all associated supports including construction management. This WBS element includes removal of equipment for clearance and accessibility, moving existing coils, modifying existing supports mounted on the vacuum vessel and installing a new external coil support structure.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	E.Perry	Erik D. Perry — Digitally signed by Erik D. Perry DN: cn=Erik D. Perry, o, ou, email=eperry@pppl.gov, c=US Date: 2015.05.06 10:20:38 -04'00'	
Responsible Line Manager (RLM)	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:07:31 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:07:50 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-8210**	**Title:** Installation of the Coil Support System (Job 8210 LOE)
WBS: 1.8.2	**Control Account Manager (CAM):** E. Perry

Scope Description;

Field supervision and oversight for Torus Assembly and construction. Includes the assembly and installation of the NSTX torus, coils systems and all associated supports including construction management. This WBS element includes removal of equipment for clearance and accessibility, moving existing coils, modifying existing supports mounted on the vacuum vessel and installing a new external coil support structure.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	E.Perry	Erik D. Perry — Digitally signed by Erik D. Perry DN: cn=Erik D. Perry, o, ou, email=eperry@pppl.gov, c=US Date: 2015.05.06 10:21:10 -04'00'	
Responsible Line Manager (RLM)	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:06:58 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:07:07 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-8250**	**Title:** CS Removal&Re-Install/Pumpdown/Bakeout (Job 8250)
WBS: 1.8.2	**Control Account Manager (CAM):** E. Perry

Scope Description;

Included in this WBS element is the removal of the existing Center Stack and installation of the NSTX Upgraded Center Stack, followed by closing up the vacuum vessel, pumping down, leak checking, bakeout and machine area scrubs to be ready for Integrated System Testing.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	E.Perry	Erik D. Perry — Digitally signed by Erik D. Perry DN: cn=Erik D. Perry, o, ou, email=eperry@pppl.gov, c=US Date: 2015.05.06 10:21:45 -04'00'	
Responsible Line Manager (RLM)	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:05:31 -04'00'	
Project Manager	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.07.22 10:05:40 -04'00'	

NSTX Upgrade Project Project Closeout Acknowledgement CD-4	
Control Account: 9417-**-8251**	**Title:** CS OH fault repairs (Job 8251)
WBS: 1.8.2	**Control Account Manager (CAM): E.Perry**

Scope Description;

Included in this WBS element are the cost associated with the NSTXU arc fault repairs that are necessary to support CD-4.

Is all work scope for this control account complete per the control account plan?

■ **Yes** ☐ **No (Describe when the work will be completed)**

Does the WBS dictionary accurately represent the work completed?

■ **Yes** ☐ **No (Describe additions and/or exclusions below)**

Acknowledgements	Name	Signature	Date
Control Account Manager (CAM)	E.Perry	Erik D. Perry — Digitally signed by Erik D. Perry DN: cn=Erik D. Perry, o, ou, email=eperry@pppl.gov, c=US Date: 2015.08.10 14:51:23 -04'00'	
Responsible Line Manager (RLM)	R.Strykowsky	Ron Strykowsky — Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.10 15:13:48 -04'00'	
Project Manager	R.Strykowsky		

Appendix C

Major External Reviews

Summary
Princeton University Advisory Committee = 11
DOE-OPA = 7
Other Management = 6
Technical Design Review = 10
Total =34

Detail List
Project Management Review (Sept 2009)
Princeton University Advisory Committee Oct 2009
CDR Conceptual Design Review (Oct 28-29, 2009)
DOE-OPA Review CD-1 Dec 2009
Princeton University Advisory Committee May 2010
CSU Peer Review (April 29, 2010)
Project Mngt Advisory Committee Sept 2010
PDR Preliminary Design Review (June 23-24, 2010)
Princeton University Advisory Committee Oct 2010
DOE-OPA Review CD-2 August 2010
External Independent Review (October 2010)
EVMS GAP analysis March 2011
CSU Peer Review (May 18, 2011)
Princeton University Advisory Committee May 2011
DCPS PDR (June 2011)
FDR Final Design Review (June 2011)
TF Fault Review (Sept 7 2011)
EVMS Mock Interviews (Sept 12-13, 2011)
EVMS Cert Review Oct 2011
Princeton University Advisory Committee Oct 2011
DOE-OPA Review CD-3 October 2011
Princeton University Advisory Committee Apr 2012
DOE-OPA Review May 2012
Princeton University Advisory Committee Nov 2012
DOE-OPA Review Dec 2012
Princeton University Advisory Committee Apr 2013
CS Magnet Review by NML Sept 2013
DOE-OPA Review Oct 2013
Princeton University Advisory Committee Nov 2013
DOE-OPA Review Feb 2014
Princeton University Advisory Committee May 2014
Aquapour review (Sept 7 2014)
Princeton University Advisory Committee Nov 2014
Princeton University /PPPL Readiness for Operations (Dec 2014)
DOE-OPA Review CD-4 May 2015

External Participant Institutions	
DOE	17
GA	8
ORNL	7
BNL	7
ANL	1
Cal Tech	1
Consultant	3
Culham	1
Abuquerque	1
MIT	8
Fermi	1
ITER IO	1
LANL	1
LBNL	1
NML	1
Princeton Univer.	2
NIST	1
SLAC	3
TJNL	3
MAST	2
Univ Wisc	1
UKAEA	1
22 Insitutions	72 Reviewers

Appendix D

Summary of Project Injuries

Date	Organization	Type	Description
6/5/09	PPPL	DART	Twisted right knee when stepping on something uneven on TFTR Test Cell floor (lost time).
3/8/13	PPPL	Recordable	Right shoulder strain after bumping into equipment along with frequent periods of awkward posture while welding.
3/11/14	PPPL	DART	Right shoulder tendinitis after shifting position while working on NSTX machine (lost time).
6/11/14	PPPL	Recordable	Irritation of right elbow area. Worker performed a number of repetitive motion activities for the NSTX Upgrade.
1/25/15	PPPL	DART	Metatarsalgia (injury to ball of right foot) after working under the NSTX-U machine (lost time).

Appendix E

Project Risk Registry

NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
1305f	1305		OH bundle - poor VPI impregnation	Engineering of the fill locations and vents will be performed as part of developing the fabrication procedure.	Evaluate condition of coil - Local dry areas could be repaired, but larger failure would require cutting OH coil from TF and rebuilding	Apr-2014	Chrzanowski	Retired	U	Significant	Moderate	cost to rewind per primavera	1279	5 month schedule impact		$ 1,279
1305g	1305		OH coil fails electrical tests	Include tests (meggar, hydro and hi-pot) at several points in the fabrication process so non-conformances can be identified and corrected as they occur.	If fault can not be repaired, Coil must be cut off and rebuilt	Apr-2014	Chrzanowski	Retired	U	Significant	Moderate	cost to rewind per primavera	1279	5 month schedule impact		$ 1,279
8200e	8200		Passive Plate Tiles/hardware need upgrading: Possibly ~3500 tiles, 70000 in^3, replacing with 2D CFC	Finalize disruprtion and thermal load analysis by FDR.	Should replcement be necessary option to defer until later in ops by limiting machine paramters (no cost/schedule impact but tech perf impact) or replace all affetced PP and tiles during the planned outage (sign cost impact little schedule impact)	8/1/2011	Tresemer	Retired	U	Significant	Moderate		1000		field removal of PP upgrade attachments and re-installPP	1000
7100a	7100	Project Management and Integration	EVMS implementation requires more project controls, supporrt for training, etc than expected	Assign experienced engineers as CAMs. Minimize the number of CAMs. New PM office.	current usage included in BAC and EAC	Dec-2011	Strykowsky	Retired	L	Marginal	likel;y	Project Manager's estimate	150		addiltional 1 fte for two years	$ 500
1001d	1001	Centerstack Plasma Facing Components	Passive Plate Tiles/hardware need upgrading: Possibly ~2050 tiles	Design and fab 2D CFC		6/22/2011	Tresemer	Retired	U	Significant	Moderate		436			436
1305d	1305		TF full bundle - poor VPI impregnation	Engineering of the fill locations and vents will be performed as part of developing the fabrication procedure.	Evaluate condition of coil - Local dry areas could be repaired, but larger failure would requireseparating quadrants and re-assy and VPI of bundle 1304-5400	Sep-2014	Chrzanowski	Retired	U	Marginal	Low		250	8		$ 250

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Appendix E (continued)

Project Risk Registry

NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
	1305	Damage to components	Inadvertent damage to centerstack assembly during movement or rigging	rigging and lifting procedures, safety discussions with staff	repair damage	Nov-2015	Chrzanowski/Strykowsky	Retired	VU			PM's estimate 4 people one month plus oversight	209	4		$ 209
1305b	1305		TF quadrant - poor VPI impregnation	Engineering of the fill locations and vents will be performed as part of developing the fabrication procedure.	Evaluate condition of coil - Local dry areas could be repaired, but larger failure would require rebuilding TF quadrant 1304-1870	Mar-2013	Chrzanowski	Retired	U	Marginal	Low	manager's estimate	200	0	repeat fabrication tasks	$ 200
1305c	1305		TF quadrant fails electrical tests	Include tests (meggar, hydro and hi-pot) at several points in the fabrication process so non-conformances can be identified and corrected as they occur.	If unable to repair short, rebuild quadrant 1304-1890	Mar-2013	Chrzanowski	Retired	U	Marginal	Low	manager's estimate	200	0	cost to cut off coil and repeat fabrication tasks	$ 200
8250b	8250		Flex bus require more than two fit-ups / reworks prior to final installation	Repeat "remove, rework, re-install"		Feb-2015	Perry	Retired	VL	Marginal	Low	Construction Manager's estimate	63 to 189	2 to 6	Same work previous done on NSTX	$ 189
7100	7100	injury promted stand down	serious injury causes 2-4 week standdown	continued focus and dilligence on safety at the daily WCC mtg, 8:30 meetings, staff meeting etc.		Mar-2015	strykowsky	Retired	u	Significant	Moderate			2 to 4		$ 188
1304a	1304	Inner TF Bundle Design and Fabrication	Poor VPI of TF bundle ***x duplicate of 1305b***	Engineering of the fill locations and vents will be performed as part of developing the fabrication procedure.	If repairs cannot be made, rebuild coil 1304-1870	n/a	Chrzanowski	Retired	U	Marginal	Low	manager's estimate	165	0	repeat fabrication tasks	$ 165
1304b	1304		TF coil fails electrical tests ****x duplicate of 1305c****	Include tests (meggar, hydro and hi-pot) at several points in the fabrication process so non-conformances can be identified and corrected as they occur.	If fault area cannot be repaired, rebuild coil 1304-1890	n/a	Chrzanowski	Retired	U	Marginal	Low	manager's estimate	165	0	repeat fabrication tasks	$ 165

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NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
2490a	2490	Relocations to Support NB2 Installation	SPRED re-design and re-installation may require more effort than estimated due to the physical constraints in the area of bay L	Start design work immediately so potential schedule impact can be accomodated if necessary.		Apr-2014	Perry	Retired	U	Marginal	Low	manager's estimate	98 to 147	0	Past experience designing and installing this diagnostic on NSTX	$ 147
2490b	2490		LOWEUS re-design and re-installation may require more effort than estimated due to the physical constraints in the area of bay L	Start design work immediately so potential schedule impact can be accomodated if necessary.		Apr-2014	Perry	Retired	U	Marginal	Low	manager's estimate	98 to 147	0	Past experience designing and installing this diagnostic on NSTX	$ 147
	7100		Generic late vendor delivery	Award contracts early ASAP, followup vendor calls, timely receipt inspection		Apr-2014	strykowsky	Retired	VU					4	$130/k/mo.	$ 130
7200a	7200	Centerstack Management	Additional reviews	Increase scope as required	currently underrunniong. No unexpected reviews remain	Sep-2013	Dudek	Retired	U	Marginal	Low	Manager's estimate	107		additional review every other year	$ 107
	7100	project stretchout	CD-4 delayed due to non-project event (ie ORA findings, non project scope (MPTS, Neutron calibr etc)	conduct ACC and ORA reviews well in advance of the ISTP tom allow rtecovery time.	continue to vcommunicate impacts to the project schedule at weekly rollover meetings.	CD-4	strykowsky	Retired	L			Project manager's estimatre	$200k/mo .	1 to 2 weeks		$ 100
6100e	6100	Additional work scope	NSTX operations does not fund work scope as listed in WBS6100 PDR	Continued diligence to assure the program office funds req'd infrastructure improvements. Additional work scope for upgrade		Sep-2014	Sichta	Retired	L	Negligible	Low	Manager's estimate	100	0		$ 100
2300a	2300	Miscellaneous small appendage reinforcements on vessel	Upgrade may increase EM loads to small items on vessel that may need reinforcement, e.g. shutters, ECH, brackets,diagnostic supports.	Design reinforcements as problem areas are identified.	Reinforcements underway for passive plates and RF feed throughs	Sep-2011	Titus	Retired	VU	Marginal	Low	project manager's estimate	100			$ 100
1304c	1304		Copper extrusion vendor has difficulty making full length conductors			5/1/2011	Chrzanowski	Retired	U	Marginal	Low	manager's estimate	100			100

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NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
1305e	1305		TF full bundle fails electrical tests	Include tests (meggar, hydro and hi-pot) at several points in the fabrication process so non-conformances can be identified and corrected as they occur.	Repair electrical short 1304-5400	Sep-2014	Chrzanowski	Retired	U	Negligible	Low		75	8		$ 75
7300a	7300	NB2 Management	Additional reviews	Increase scope as required		2/2/2011	Stevenson	Retired	U	Negligible	Low	Manager's estimate	75		additional review every other year	75
7700a	7700	HP Allocations	Volatility of overhead rates	ETC reflects revised cost			Strykowsky	Retired	L	Negligible	Low	Project Manager's estimate	65	0	3% variation	$ 65
7700b	7700		Volatility of base estimates for the allocated cost centers	ETC reflects revised cost			Strykowsky	Retired	L	Negligible	Low	Project Manager's estimate	65	0	3% variation	$ 65
1001c	1001	Centerstack Plasma Facing Components	Tiles require unforseen machining	If schedule critical, and in-house machinining will not suffice, seek external machining sources. Additional machining time added to WAF	1302-1500	Jun-2014	Tresemer	Retired	L	Negligible	Low	prior experience on NSTX	15 to 60	1 to 4	3 machinists for 1 to 4 weeks	$ 60
1200a	1200	Centerstack Structural Supports	All interferences with existing equipment have not been identified	Field audit of interferences is included in estimate. audit included in base estimate		2/2/2011	Mangra	Retired	U			manager's experience	60	0	6 weeks of engineer and designer	60
8250a	8250	Centerstack Removal and Re-installation / Pumpdown / Bakeout	Vacuum seals don't pass leakcheck	Lift centerstack out, rework seals, re-install centerstack		Feb-2015	Perry	Retired	VU	Negligible	Low	Construction Manager's estimate	28 to 56	1 to 2	Same work previous done on NSTX	$ 56
6100d	6100	Loss of key personnel	Loss of key personnel	hire replacement and assess schedule impact		Sep-2014	Sichta	Retired	VU	Significant	Low	Manager's estimate	10 to 50	9		$ 50
1306a	1306	Inner PF Coils Design and Fabrication	Poor impregnation	Engineering of the fill locations and vents will be performed as part of developing the fabrication procedure.	Local dry areas can be repaired. Extensive areas of poor VPI may require rewinding new coil. 1306-5050	Jan-2014	Chrzanowski	Retired	U	Negligible	Low	manager's estimate	10 to 50	0	repeat fabrication tasks	$ 50

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Appendix E (continued)

NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
1306b	1306	Inner PF Coils Design and Fabrication	Coil fails final acceptance tests.	Include tests (meggar, hydro and hi-pot) at several points in the fabrication process so non-conformances can be identified and corrected as they occur.	If coil cannot be repaired, a new coil will need to be wound. 1306-5050	Jan-2014	Chrzanowski	Retired	U	Negligible	Low	manager's estimate	50	0	repeat fabrication tasks	$ 50
1301a	1301	Outer TF Coil Repairs	After press mold operation, numerous dry areas are found	Engineering of the fill locations and vents will be performed as part of developing the fabrication procedure.	Attempt local repair; if unsuccessful, rebuild coil 1301-0060	May-2013	Chrzanowski	Retired	U	Negligible	Low	manager's estimate	50	0	repeat existing tasks	$ 50
1301b	1301		Coil does not pass final acceptance tests	Include tests (meggar, hydro and hi-pot) at several points in the fabrication process so non-conformances can be identified and corrected as they occur.	Attempt local repair; if unsuccessful, rebuild coil 1301-0060	May-2013	Chrzanowski	Retired	U	Negligible	Low	manager's estimate	50	0	repeat existing tasks	$ 50
1303a	1303	TF Joint Test Stand and Testing	Significant change in TF design concept	Perform additional work		2/1/2011	Kozub	Retired	U	Negligible	Low	manager's estimate	10 to 50		past experience	50
1303b	1303		Increased number of redesign/retest cycles	Perform additional work		2/1/2011	Kozub	Retired	U	Negligible	Low	manager's estimate	10 to 50		past experience	50
7100	7100	core competencies-critical staff	critical skills lost (due to illness,VSP,retirement etc)	Cross train and develop backup staff	reduced likely hood	Mar-2015	strykowsky	Retired	VU	Significant	Moderate	schedule impact of 2 weeks on critical path		2		$ 45
7710a	7710	Direct Allocations	Volatility of head rates	ETC reflects revised cost			Strykowsky	Retired	L	Negligible	Low	Project Manager's estimate	65	0		$ 43
7710b	7710		Volatility of base estimates for the allocated cost centers	ETC reflects revised cost			Strykowsky	Retired	L	Negligible	Low	Project Manager's estimate	65	0		$ 43
8250c	8250		Umbrella lids require more than two fit-ups / reworks prior to final installation	Repeat "remove, rework, re-install"		Feb-2015	Perry	Retired	VL	Negligible	Low	Construction Manager's estimate	14 to 42	1 to 2	Same work previous done on NSTX	$ 42

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Appendix E (continued)

Project Risk Registry

NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
1000b	1000	Centerstack Analytical Support	Analysis indicates a minor component needs upgrade that previously hasn't been identified - weld details, details that are inconsistent with the Pro-E model	Identify these areas early with site surveys and as-builts		Jun-2014	Titus	Retired	VU	Negligible	Low	manager's experience	10 to 40	0	manager's estimate	$ 40
1000a	1000	Centerstack Analytical Support	Analysis indicates a significant component needs upgrade that previously hasn't been identified	Maintain upgrades of the model and keep ahead of the scenario changes		Jun-2014	Titus	Retired	VU	Negligible	vu	manager's experience	10 to 40	0	manager's estimate	$ 40
8200d	8200		Realign Coils - This is in case the coils spring or change shape after releasing them from their existing clamps. This could afect the alignment of all any coil mounted to the vessel wall/ribs.	Metrology - new clamps	Not Required	Sep-2013	Perry	Retired	U	Negligible	Low	Manager's estimate	40	0		$ 40
8200c	8200		Realign vacuum vessel - This is in case the vessel springs or changes shape after cutting the new port opening. This could affect the alignment of all the vessel internals mounted to the vessel wall.	Metrology	Not Required		Perry	Retired	L	Negligible	Low	Manager's estimate	40	0		$ 40
8200b	8200		Damage to coil insulation during removal - This is in case we accidentally nick or gouge the outer insulation.	repair coil	Not Required	Apr-2014	Perry	Retired	VU	Negligible	Low	Coil engineer (Chrzanowski) estimate	40	0		$ 40
7400a	7400	Health Physics Support	Unplanned overtime	Increase scope as required included in job		2/2/2011	Stevenson	Retired	L			Project Manager's estimate	35		additional 10%	35
1303c	1303		Unexpected technical challenges in implementing testing apparatus and procedures	Perform additional work		2/1/2011	Kozub	Retired	VU	Negligible	Low	manager's estimate	0 to 30		past experience	30

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Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
6100c	6100	Data Acquisition rate	Data acquisition takes too long	Upgrade additional data acq systems and/or networks, revise software		Sep-2014	Sichta	Retired	VU	Marginal	Low	Manager's estimate	5 to 25	0		$ 25
2300c	2300		Diagnostic/waveguide requires more analysis to qualify	Expand analysis models beyond those used in the scoping study		2/2/2011	Titus	Retired		Negligible	Low		25			25
1002a	1002	Passive Plate Analysis	Halo and New/other disruption loads are beyond the capacity of the present hardware	Size modifications based on calculations and implement	Reinforcements underway for passive plates and RF feed throughs	Sep-2011	Titus	Retired	VU	Negligible	Low	Project Manager's estimate	5 to 20	0	1 to 4 weeks of designer	$ 20
3400a	3400	Gas Delivery system mods for Centerstack upgrade	Fueling lines do not adequately deliver gas because of occlusions or leaks	Replace gas delivery line. Minor fix if req'd	3400-0052	Sep-2014	Blanchard	Retired	VU	Negligible	Low	Project manager's estimate	10	0	Similar installation on NSTX	$ 10
1305h	1305		Unable to completely remove temporary spacer between OH and TF after completion of fabrication	Administrative controls during operation requiring OH and TF to be powered together	1305-8700	Mar-2014	Chrzanowski	Retired	U	Marginal	Low		0	1		$ 3
1302a	1302	Centerstack Assembly	Components do not arrive when required	If schedule is critical, OT or second shift would be required to regain schedule	1302-1500	Jun-2014	Chrzanowski	Retired	U	Negligible	Low		0	0		$ -
1307a	1307	Centerstack Casing Assembly Design and Fabrication	Components arrive late	OT required to recover schedule	1307-2030	Apr-2014	Chrzanowski	Retired	U	Negligible	Low		0	0		$ -
7100rs	7100	Project Schedule	Opportrunity to accelerate the schedule by emplying 2 shift operation in the CS fab and by applying cost underruns to acxcelerate scope	Jim chrzanowski to consider two shift ops Strykowsky to identifying schedule accel tasks	none	Sep-2013	Chrzanowski/Strykowsky	Retired	L	Significant		Based on schedule analysis of critical path and at least 3 months savings x standing army cost (strykowsky)	-750	-3 mo.		$ -
1200b	1200		Engineering total man-hours >1 engineer	obtain requested resources		Sep-2011	Mangra	Retired	VL	Negligible	Low		0			$ -
1200c	1200		Schedule is front end loaded	obtain requested resources		Sep-2011	Mangra	Retired	VL	Negligible	Low		0			$ -

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Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
8200rs	8200	Construction	Opportunity to factor in efficiencies into the construction plan	Erik to do bottom-s up estimate factoring in input from viola, raftopolous, and jos winston	none	Oct-2011	Perry/Strykowsky	retired	L	Significant		Based on at least 10% savings (strykowsky)	0			$ -
1305a	1305	OH Coil Design and Fabrication	No vendor bids for OH/TF fabrication	Fabricate coil in-house [Suggest having bid process include both domestic and international] PPPL to fab		OH coil fabrication	Chrzanowski	Retired	U							0
2440a	2440	Beamline Refurbishment	Further inspections may require additional parts and labor	Inspect all parts promptly so damaged ones can be identified early - all parts and labor now in job estimate		2/2/2011	Denault	Retired	U			project manager's estimate	50			0
2450b	2450		Heat load may be too high	Remake He lines - not a concern		2/2/2011	Denault	Retired	U			project manager's estimate	50	0		0
2440b	2440		Existing copper parts may be reusable (except for the dump)	Negative risk - reduce scope of job - job estimate now includes reduced scope		FY10 PDR	Denault	Retired	L			project manager's estimate	-234			0
7200b	7200		Availability of key personnel: Chrzanowski, Mangra, Titus	Chrzanowski by Heitzenroeder and Kalish; Mangra by Smith: Titus by Brooks and Heitzenroeder - back-up persons identified for key personnel		FY10 PDR	Dudek	Retired								0
2490c	2490		MPTS Beam Dump Window re-design and re-installation may require more effort than estimated due to the physical constraints in the area of bay L	Preliminary design work started to layout MPTS and included VV modifdactions and interfaces.- Job 4500 estimate included to provide larger Bay L port and MPTS interfaces.		FY11 FDR	Jones	Retired	U			Engineering estimate	included in NSTXU cost		Past experience designing and installing this diagnostic on NSTX	0
2460a	2460	NB Armor	CFC tiles needed for thermal/structural reasons	Add requirement for redundant plasma control to eliminate need for CFC tiles - Now in job		FY10 PDR	Priniski	Retired	L							0

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Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
2480a	2480	NB2 Duct and VV Mods	Beam too close to bellows/duct	Include molybdenum shielding in estimate - Bay K port plug provides larger free apeture than BL. Some Moly shield for bellows included in job.		FY10 PDR	Priniski	Retired	L			project manager's estimate	30 to 60	0	Past experience on NSTX	0
2480d	2480		Previous fabricators of rectangular bellows not available	Locate alternate vendors - RFQ with multiple vendors to access vendor and cost for PDR.		Issue requisition for bellows fabrication	Priniski	Retired	U			Project Manager's estimate	10 to 100			0
2480b	2480		Difficulty machining vessel	Double estimate for this portion of the job - several methods exist for cutting and job estimate was increased for least efficient process.		Vessel machining	Priniski	Retired	L			project manager's estimate	10 to 70	1 to 8	Past experience on NSTX	0
2480c	2480		J-K cap may not be able to be installed in one piece	Include removal of one TF outer leg (to facilitate access) in the baseline estimate - now in job			Priniski	Retired	U							0
2470b	2470		Old 100 micron fiber cables that are proposed to be used may not be in good condition	Test a prototype with a 62.5 micron cable fused to 100 micron cable - sufficient 100 micron cable located on-site		FY11 FDR	Ramakrishnan	Retired	U			project manager's estimate	50		Past experience in installing the NB1 line up for NSTX	0
2470a	2470	NB Power System	Old RCA tubes are being used and may need a tune-up	Use the 8 additional tubes from TFTR - replacements available			Ramakrishnan	Retired	U						Budgetary quotes received for Tiax and other cables and used in estimates	0
6100a	6100	Central Instrumentation and Control	Volume of data from diagnostic camera systems exceed capability of network, storage, and backup systems	Install 10 Gb networks and enhance storage and backup systems		FY10 PDR	Sichta	Retired	U	Marginal	Low	Engineering estimate	30 to 200		Similar work at PPPL	0
6100b	6100		EPICS data acquisition takes too long	Include in the base job the upgrade of some data acquisition systems (CAMAC)		FY10 PDR	Sichta	Retired	VL	Marginal	Moderate	Engineering estimate	10 to 100		Similar work at PPPL	0

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Appendix E (continued)
Project Risk Registry

NSTX Upgrade Project Risk& Opportunity Registry, rev 26 3/20/2015

Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
2300b	2300		Diagnostic/waveguide hqas a present weakness that hasn't been seen in operation	Reinforce		2/2/2011	Titus	Retired		Negligible	Low		0			0
8200a	8200	Centerstack and Coil Structure Installation	Longer time to remove diagnostics for access	- incorporated into base plan			Viola	Retired	L							0
8200c	8200		remove LLD and replace with existing OD tiles	Perform disruption analysis on LLD or program decision on limiting operation.INCLUDE IN BASELINE			Viola	Retired	L			Manager's estimate	0			0
2450a	2450	NB2 Services	Availability of V. Garzotto	Desandro / Denault could do this work-replacements available				Retired								0
1001e	1001	Centerstack Plasma Facing Components	May be able to use ATJ on CS VS instead of 2D CFC. Depends on fastening needs			6/22/2011	Tresemer	Retired	U			Possible outcome of thermal analysis. Is unlikely.	-75			-75
7100b	7100		FY2014 overhead rates	Continue to ensure that outyear rates are conservative		Apr-2014	Strykowsky	Retired	L			Project Manager's estimate	-1000	0		$ (1,000)
	2420		Ion sources Use existing 6 sources	factored into baseline via ecp-004			strykowsky	Retired								$ (1,000)
7100b	7100		FY2015 overhead rates	Continue to ensure that outyear rates are conservative		Apr-2014	Strykowsky	open	L			Project Manager's estimate	tbd	0		
1001a	1001	Centerstack Plasma Facing Components	Tiles not delivered on time	If schedule critical, install tiles in vessel.	1001-0066	Jun-2014	Tresemer	Retired	U			prior experience on NSTX	0	0		
1001b	1001	Centerstack Plasma Facing Components	Special diagnostics for tiles not received on time	If schedule critical, install tiles in vessel.	4100-0056	Jun-2014	Tresemer	Retired	U			prior experience on NSTX	0	0		
CD0-a			Uncertain of ability to find a cost effective TF joint that works at higher fields	Perform extensive analysis (all operating scenarios) for new joint designs			Dudek	Retired								
CD0-b			Little room to re-enforce outer TF legs and umbrella structure to handle higher loads	Perform detailed design			Dudek	Retired								

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Appendix E (continued)

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Number	CA	Job Title	Risk Description	Mitigation Plan	Corrective Action if Risk Occurs	Deadline to Retire Risk or Absorb Impact	Owner	Current Status	Likelihood of Occurrence	Con-sequences	Risk Ranking	Basis of Estimate	Cost Impact ($K)	Critical Path Schedule Impact (weeks)	Cost and Schedule Impact Calculation Basis	Cost considered
															Retired=	$ 6,243
															Open=	$ -
CD0-c			The vacuum vessel may need to be reinforced to accommodate higher loads				Dudek	Retired								
CD0-d			Uncertain of level of effort required to decontaminate TFTR NB				Stevenson	Retired								
CD0-e			Uncertain of the commercial availability of high voltage switch-tubes				Stevenson	Retired								
CD0-f			Uncertain of the commercial availability of cabling and terminations for the 100kV accelerator system				Stevenson	Retired								
1001d	1001	Centerstack Plasma Facing Components	Outboard Divertor tile and hardware replacement may be required for extreme operating scenarios	Should replacement be necessary, defer until later in ops by limiting machine paramters (no cost/schedule impact)		8/2/2011	Tresemer	Retired	VU			Retired. Existing OBD tiles will be used inplace of the LLD.				

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Appendix F

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
1	1.7	7700	Combine CA 770 and 7710 into one CA (7710) Direct Allocations	4/25/2011	3 Project Manager			$77,317	$16,992	Approved
2	1.6	6100	Move the baseline start date for task 6100-0041 to 12 April 2012	6/8/2011	3 Project Manager			$77,317	$16,992	Approved
3	1.6	6100	Reduce man-hours on task 6100-001. Add this budget as M&S on task 6100-0049D.	9/10/2011	3 Project Manager			$77,317	$16,992	Approved
4	1.1 1.2 1.8	1304 8200 8210 2420 2490	1- CA 1304 change to TF procurement (cost/schedule) 2- CA 8200 re-structured and split into two CA's (8200/8210) 3- Remove four tasks from NB Source CA 2420 4- Task accelaration	11/10/2011	2 Federal Project Director	963	963	$78,280	$16,029	Approved
5	1.5	5501 5200 5000	Update the Work Breakdown Structure/Dictionary in the Project Execution Plan to ensure that a single Control Account does not occur at more than one WBS element	10/6/2011	3 Project Manager		963	$78,280	$16,029	Approved
6	1.7 1.8	7100 8200 8250	Various changes to Control Accounts 7100 (move labor), 8200/8250 (delete WPs and convert to PPs)	11/21/2011	3 Project Manager	-3	960	$78,277	$16,032	Approved
7	1.5	5000	Convert task 531-005 held in Planning Package to discrete tasks	11/30/2011	3 Project Manager		960	$78,277	$16,032	Approved
8	1.8	8200 8210	Move budget/task (8200-0017A) for purchase of two welding machines from oversight job (8210) to field work job (8200). Change EVT to % Complete.	12/2/2011	3 Project Manager		960	$78,277	$16,032	Approved
9	1.3	3300	Control Account 3300: Convert WP 3300-125 EVT from Planning Package to % complete.	12/13/2011	3 Project Manager		960	$78,277	$16,032	Approved
10	1.5	5000	Convert EVT for activity 531-013 to % complete	1/13/2012	3 Project Manager		960	$78,277	$16,032	Approved
11	1.1	1002	Control Account 1002. Add scope (cost/schedule) as shown on attached WAF to support reinforcement of passive plates. Change CA 1002 CAM to Neway Atnafu.	1/23/2012	2 Federal Project Director	178	1138	$78,455	$15,854	Approved
12	1.1 1.2	1304 1305 2480	Delete several unnecessary activities from CA 1304 Inner TF Bundle. Add several activities (cost/schedule) to CA 1305 to accomodate sandblast and prime of OH conductor. Reduce budget on task 2480-0057.	2/7/2012	2 Federal Project Director	-11	1127	$78,444	$15,865	Approved
13	1.8	8200 8210	Move task 8200-0017 from Control Account 8210 to Control Account 8200.	12/19/2011	3 Project Manager		1127	$78,444	$15,865	Approved
14	1.2	2485	Change the EVT for task 2485-0044A to C (% complete)	1/9/2012	3 Project Manager		1127	$78,444	$15,865	Approved
15	1.1	1305	Add activities (cost/schedule) to accomplish Aquapour test recommended at FDR	2/22/2012	2 Federal Project Director	31	1158	$78,475	$15,834	Approved
16	1.2	2300	Engineering and Analysis work to support adding compliance to the HHFW antennas. New CAM = Bob Ellis		2 Federal Project Director		1158	$78,475	$15,834	OPS Scope
17	1.2	2425	Neway Atnafu will replace Martin Denault as the Control Account Manager for Control Account 2425 BL Relocation.	1/24/2012	3 Project Manager		1158	$78,475	$15,834	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
18	1.2	2450	Resource change for several activities in Control Account 2450, and a change to the start dates for several LOE tasks.	1/26/2012	3 Project Manager	-10	1148	$78,465	$15,844	Approved
19	1.1 1.8	1301 8200	Move tasks for drilling additional holes in outer TF flags (tasks 1301-0300 and 1301-0310) from Control Account 1301 to Control Account 8200	2/21/2012	3 Project Manager		1148	$78,465	$15,844	Approved
20	1.2	2425	Change the start and finish dates for the three LOE tasks.	2/21/2012	3 Project Manager	-6	1142	$78,459	$15,850	Approved
21	1.2	2425	Replanning of work scope in Control Account 2425 to better fit project timing. Should equate to a slight budget reduction.	3/12/2012	3 Project Manager	-51	1091	$78,408	$15,901	Approved
22	1.5	5200	Re-planning of Control Account 5200 for Digital Coil Protection	5/1/2012	2 Federal Project Director	27	1118	$78,435	$15,874	Approved
23	1.2	2440	Transfer responsibility of Control Account Manager (CAM) from Martin Denault to Mark Cropper for Control Account 2440 2nd NBI Beamline	2/24/2012	3 Project Manager		1118	$78,435	$15,874	Approved
24	1.1	1307	Replace task 1307-2030 Fabricate CS Casing with five (5) new tasks consistent with contract award	3/28/2012	2 Federal Project Director	409	1527	$78,844	$15,465	Approved
25	1.2 1.8	2475 8200	In Control Account 2475 add steps to the schedule for EPICS timing and Control Interface. In Control Account 8200: Delete task 8200-0102C	4/2/2012	2 Federal Project Director	122	1649	$78,966	$15,343	Approved
26	1.1 1.7 1.8	1001 7100 8250	Change M&S budget on tasks 1001-0066 and 1001-0066F in Control Account 1001. Also this ECP increases FY2012 resources for Control Account 7100 (Project Management & Integration).Delete redundant tasks from Control Acct. 8250.	3/21/2012	2 Federal Project Director	210	1859	$79,176	$15,133	Approved
27	1.1 1.8	5000 1302 1304 1305 1307 8200	Update (replanning) of Control Accounts 1302, 1304, 1305, 1307 including additional tasks and updated resources. Delete Planning Package 8200-PP01A; work not required.	5/1/2012	2 Federal Project Director	22	1881	$79,198	$15,111	Approved
28	1.7	7300	In Control Account 7300 - Delete task 7300-13 Support of OPA Review	3/27/2012	3 Project Manager	-86	1795	$79,112	$15,197	Approved
29	Milestone PEP		In PEP: Re-define Level II milestone change ref "Friction stir weld coil leads..." In Project Schedule: Re-define activity 1070 to read:RECEIVE FIRST DELIVERY MACHINED INNER TF CONDUCTOR - 30 JUN 2012	4/3/2012	2 Federal Project Director		1795	$79,112	$15,197	Approved
30	1.7	7300	In Control Account 7300 (NB2 Management) delete activity 7300-22.	5/2/2012	2 Federal Project Director	-86	1709	$79,026	$15,283	Approved
31	1.2 1.1	2490 1002 2440	CA: 1002 Add drafting support CA: 2440 Delete tasks for exit spool piece CA: 2490 Add drafting support and tasks for locating TMP rack on 119' platform	5/23/2012	2 Federal Project Director	-165	1544	$78,861	$15,448	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
32			Not used				1544	$78,861	$15,448	
33	1.1 1.7	1000 7710	In Control Account 1000 increase the Title III Analysis Support task (LOE) to 900 man hours/FY. This equates to 75 hrs/mo from June 2012 through September 2014. Reduce FY12 and FY13 HP Allocation task in Control Account 7710.	6/14/2012	2 Federal Project Director	258	1803	$79,120	$15,189	Approved
34	1.1	1304	Change the EVT for several tasks in CA 1304 from 0-100 to % complete. The thought was that milestone payments would be made; however, accruals have been taken based on completion of work and we want to ensure we earn the appropriate value.	6/8/2012	3 Project Manager		1803	$79,120	$15,189	Approved
35	1.1	1305	In Control Account 1305 task 1304-1510 had baseline dates of 2Oct12 through 19Sept13. With the early start of fabrication this task requires date changes to Start: 1May2012 through Finish: 31Aug2012.	6/21/2012	2 Federal Project Director	-2	1801	$79,118	$15,191	Approved
36	1.1	1304	In Control Account 1304 Subcontract S011001 was amended to have Major Tool straighten some of the conductors. This task added an additional $66,260.00 to the contract. This change will add this additional cost in task 1304-1000.	6/21/2012	2 Federal Project Director	66	1867	$79,184	$15,125	Approved
37	1.1	1001	Protective measures for the PF-1C coil canister.	7/20/2012	2 Federal Project Director	464	2332	$79,649	$14,660	Approved
38			Not Used		3 Project Manager		2332	$79,649	$14,660	Not yet submitted for Approval
39	1.1	1300 1301 1305 4100	Additional budget to jobs in CA's 1300, 1301 and 1305. Resources are needed for these tasks that were not previously budgeted.	6/26/2012	2 Federal Project Director	689	3021	$80,338	$13,971	Approved
40	1.4	6100	Physics (Stefan) identified new workscope for Diagnostics. This ECP represents the portion of that which Central I&C can service.				3021	$80,338	$13,971	OPS Scope
41	1.5	5000	PF1 feed changes		2 Federal Project Director		3021	$80,338	$13,971	OPS Scope
42	1.8	8210	Reschedule and re-budget task 8200-0012D "Reinstallation Oversight".	7/3/2012	2 Federal Project Director	159	3180	$80,497	$13,812	Approved
43	1.8 1.2	8200 2490	Additional tasks for Control Accounts 8200 and 2490. Delete 3 tasks from CA 2490.	7/30/2012	2 Federal Project Director	178	3358	$80,675	$13,634	Approved
44	1.2	2425	The HVAC duct over the door between the TFTR and NSTX Test Cells was removed to allow the move of the second neutral beam into the NTC. When this duct is permanently re-installed it should be mounted higher on the wall so it will not interfere with future use of this doorway.	7/16/2012	2 Federal Project Director		3358	$80,675	$13,634	Not yet submitted for Approval

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
45	1.1	1300 1301 1302 1304 1305 1306 1307	Re-estimating of remaining Center Stack Work	8/15/2012	2 Federal Project Director	1466	4824	$82,141	$12,168	Approved
46	1.1	1001	Delete tasks 1001-0078 and 1001-0082 in Control Account 1001. These two tasks are redundant.	7/24/2012	2 Federal Project Director	-43	4782	$82,099	$12,210	Approved
47	1.1 1.2 1.3	2450 2480 3200	Change Control Account Manager (CAM) for several jobs: 2450: from Denault to Neway Atnafu 2480: from Denault to Bill Blanchard 3200: from Denault to Neway Atnafu	8/8/2012	3 Project Manager		4782	$82,099	$12,210	Approved
48	1.1	1200	Updated estimated costs are more than original budget for several tasks. Request additional budget.	8/20/2012	2 Federal Project Director	169	4951	$82,268	$12,041	Approved
49	1.5	5501 1200	Additional scope (cost/schedule) for Control Account 5501 analysis tasks and additional oversight/documentation time for Control Account 1200	10/5/2012	2 Federal Project Director	497	5448	$82,765	$11,544	Approved
50	1.6	6100	Add additional budget to oversight task 6100-0000	9/4/2012	2 Federal Project Director	38	5486	$82,803	$11,506	Approved
51	1.1	1305	Add activity 1305-0003 to re-design and manufacture flanges for the TF Quadrant Mold that will allow for complete closure and sealing of the mold	7/19/2012	2 Federal Project Director	10	5496	$82,813	$11,496	Approved
52	1.2	2480	Convert Planning Package 2480-0076 to discrete activities	8/28/2012	3 Project Manager		5496	$82,813	$11,496	Approved
53	1.2	2440	Delete tasks 2440-0014 and 2440-0024 from Control Account 2440	9/19/2012	2 Federal Project Director	-125	5371	$82,688	$11,621	Approved
54	1.2	2490	Delete tasks 24910470 and 24910480 from Control Account 2490	9/24/2012	2 Federal Project Director	-36	5335	$82,652	$11,657	Approved
55	1.4	4500	Add scope for analysis/design/fabrication/installation of tFIDA	12/4/2012	2 Federal Project Director	192	5527	$82,844	$11,465	Approved
56	1.2	2440 2475	Delete unnecessary task from Control Account 2440. In Control Account 2475 add steps to the schedule for LCC & Low Voltage Power Supply refurbishment. In Control Account 2475 add steps to the schedule for Display Software up-grade.	10/19/2012	2 Federal Project Director	59	5586	$82,903	$11,406	Approved
57	1.8	8200	Install 6 small ports on NSTX Vacuum Vessel	12/4/2012	2 Federal Project Director	97	5683	$83,000	$11,309	Approved
58	1.2 1.1	2460 1001	For Control Account 1001 the contract for the machining for Batch 1 of the PFCs came in under budget by ~$90K. For Control Account 2460 there is an increase in job scope	12/4/2012	2 Federal Project Director	-31	5651	$82,968	$11,341	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
59	1.1	1001	Move BL start date for task 1001-0066F to 12/3/2012 while task is being re-planned.	11/12/2012	3 Project Manager		5651	$82,968	$11,341	Approved
60	1.2	2450	The baseline budget for Control Account 2450 is not sufficient to perform the remaining work scope. This ECP will be used to cover the difference between the cost estimate for the remaining work and the original budget.	1/24/2013	2 Federal Project Director	221	5872	$83,189	$11,120	Approved
61	1.1	1305 1304	Add tasks to cover additional work on TF quadrant mold and to perform an in-line braze test (OH). Change BL dates on two other tasks.	12/17/2012	2 Federal Project Director	14	5886	$83,203	$11,106	Approved
62	1.8 1.7	8200 8210 7300 7200	For Control Account 8200/8210 - add re-work of parts received from other WBS elements. Delete two tasks from Management Job 7300 and one task from Management Job 7200.	12/20/2012	2 Federal Project Director	240	6126	$83,443	$10,866	Approved
63	1.5	5200	Change BL start and finish dates on the Water PLC portion of the DCPS (5200) job.	12/10/2012	2 Federal Project Director	2	6128	$83,445	$10,864	Approved
64	1.5	5501	Control Account 5501 has been assigned to a new CAM. The CAM has overhauled the schedule which requires additional budget. All tasks that are currently "in-progress" will be stopped as of the end of February 2013 and the new schedule will be used moving forward.	3/29/2013	2 Federal Project Director	319	6448	$83,765	$10,544	Not yet submitted for Approval
65	1.5	5501	Change Control Account Manager (CAM) on Control Account 5501 Coil Bus Runs to Neway Atnafu	12/20/2012	3 Project Manager		6448	$83,765	$10,544	Approved
66	1.1	1002	Passive plate re-inforcement	1/24/2013	2 Federal Project Director	197	6644	$83,961	$10,348	Approved
67	1.2	2490	Remove several activities from Control Account 2490 which are no longer required since the SPRED diagnostic will not be re-installed	1/31/2013	2 Federal Project Director	-60	6584	$83,901	$10,408	Approved
68	1.1	1302 1305 1306	Correct baseline dates for various future Critical Path activities to make them consistent with the baseline schedule and milestones. Also, replan activity 1306-5050 for the PF coil procurement.	1/17/2013	2 Federal Project Director	18	6602	$83,919	$10,390	Approved
69	1.1	1001	Reduce total budget on task 1001-0066F to $142,000 (a reduction of $146,064.80)	1/17/2013	2 Federal Project Director	-146	6456	$83,773	$10,536	Approved
70	1.1	1305	Move baseline dates for task 1305-2620 "Fab and deliver OH Mold" (this is a zero cost change)	1/28/2013	3 Project Manager		6456	$83,773	$10,536	Approved
71	1.7	7400 7710	Reduction of 10% in remaining HP support activities and HP direct allocations due to reduced need	1/31/2013	2 Federal Project Director	-133	6322	$83,639	$10,670	Approved
72	1.2	2450	Control Account Manager restructuring of job post CAM change. No increase in budget.	3/5/2013	2 Federal Project Director	0	6322	$83,639	$10,670	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
73		1304	NOT USED				6322	$83,639	$10,670	
74	1.2	2480	S-FLIP Port Installation and Reinforcement	3/1/2013	2 Federal Project Director	165	6487	$83,804	$10,505	Approved
75	1.1	1200	NOT USED				6487	$83,804	$10,505	
76	1.1	1001	Adjust the baseline dates of various future tasks in job 1001 CS Plasma Facing Components (small cost increase due to tasks pushed into FY14)	3/21/2013	2 Federal Project Director	3	6490	$83,807	$10,502	Approved
77	1.8	8200	In Control Account 8200 add additional scope for installation of umbrella arch reinforcements which is not included in the existing estimate.	3/19/2013	2 Federal Project Director	74	6564	$83,881	$10,428	Approved
78	1.1	1300 1305	Updated resources added for Control Account 1305 to cover the VPI's through the full TF. Added resources for Commissioning of the OH Winding Station. Additional resources added to the LOE job 1300 to cover Engineering Support and Drafting/Title III support.	3/22/2013	2 Federal Project Director	476	7040	$84,357	$9,952	Approved
79	1.1	1200	In Control Account 1200. The bolted connection between the lower lid and the pedestal require re-design and analysis.	4/19/2013	2 Federal Project Director	8	7048	$84,365	$9,944	Approved
80	1.8	8250	Delete Planning Package 8250-PP01A "CS Analysis Update". This scope is not needed in this Control Account.	4/25/2013	2 Federal Project Director	-49	6999	$84,316	$9,993	Approved
81	1.1	1306	Delete current task 1306-5050A for the PF Coil Procurement and replace with new task 1306-5050B which shows the current contract price/schedule.	4/26/2013	2 Federal Project Director	-19	6980	$84,297	$10,012	Approved
82	1.1	1300	Budgeted time required for Control Account 1300 task 1300-0012 Engineering Support needs to be increased 300 hrs. per month through Sept. 2013.	5/9/2013	2 Federal Project Director	388	7368	$84,685	$9,624	Approved
83			NOT USED			21	7389	$84,706	$9,603	
84	1.2	2450	The winning bid for the NBI Pipeline construction contract was $668,210. This is more than the $500,000 originally estimated by $168,210. Plus, due to safety concern for this complex construction activity, 1 PPPL personnel is decided to monitor and assist the contractor activities at all times, in addition to the supervision by Technical Rep, QC and ES&H.	5/15/2013	2 Federal Project Director	223	7612	$84,929	$9,380	Approved
85	1.8 1.2 1.1	1302 2490 8200 8250	Additional tasks required in Control Account 8250 required for the re-assembly of the Centerstack and Installation into NSTX. These tasks are off-set by several tasks being deleted in Control Accounts 1302, 2490 and 8200.	6/3/2013	2 Federal Project Director	1	7614	$84,931	$9,378	Approved
86	1.5	5200	This ECP is a re-planning of the remaining tasks for Control Account 5200. The remaining tasks represent a reduction in cost to complete the DCPS work scope.	5/30/2013	2 Federal Project Director	-162	7452	$84,769	$9,540	Approved
87	1.2	2480	Delete unnecessary tasks from Control Account 2480. Add new steps for the fabrication, testing, and assembly of the Transition Duct.	6/3/2013	2 Federal Project Director	-23	7429	$84,746	$9,563	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
88	1.1	1200	In Control Account 1200: Require high strength hardware for all Umbrella Upper/Lower Lid Connections requiring and increase in M&S for these tasks.	6/18/2013	2 Federal Project Director		7429	$84,746	$9,563	Approved
89	1.1	1305	In job 1305 add two additional tasks. 1) Additional OH conductor 2) Provide dehumidifier for CS HiBay	6/18/2013	2 Federal Project Director	31	7460	$84,777	$9,532	Approved
90	1.7	7200	Additional additional task to Control Account 7200 to cover the estimated costs of attending the SOFE Conference	6/26/2013	2 Federal Project Director	142	7602	$84,919	$9,390	Approved
91	1.3	3300	Control Account 3300: Purchase additional bakeout system power supplies/accessories	9/13/2013	2 Federal Project Director	81	7683	$85,000	$9,309	Approved
92	1.5	5200	Control Account 5200 requires additional scope to support: 1) Computer Division Support Activities, 2) Additional Computer Division project oversight, 3) Evaluation of additional scope requirements, and 4) Additional software design.	7/31/2013	2 Federal Project Director	45	7728	$85,045	$9,264	Approved
93	1.2	2425 2450	Change the Control Account Manager for Control Accounts 2425 and 2450 from Neway Atnafu to Mark Cropper	7/23/2013	3 Project Manager		7728	$85,045	$9,264	Approved
94	1.5	5501	Increased budget need on several activities in Control Account 5501 as a result of a bottom up estimate. The estimate was completed after the design maturity has increased which has given a clearer picture of the man-power and procurement needs for the Control Account future activities.	8/21/2013	2 Federal Project Director	146	7874	$85,191	$9,118	Approved
95	1.1	1002	PCHERS passive plate design/fabrication	9/3/2013	2 Federal Project Director	357	8231	$85,548	$8,761	Approved
96	1.2	2470	For Control Account 2470 a budget increase is necessary due to sub-contract quotes being more than budgeted cost for activity 247000750 "Installation of 2nd NBI Raceway".	8/21/2013	2 Federal Project Director	157	8388	$85,705	$8,604	Approved
97	1.1	1300	Add additional budget to Control Account 1300 to extend LOE Engineering Support	9/30/2013	2 Federal Project Director	264	8652	$85,969	$8,340	Approved
98			NOT USED				8652	$85,969	$8,340	
99	1.1	1305	The results of a bottom-up estimate and job review for Control Account 1305 added additional scope/budget per attached .pdf.	9/30/2013	2 Federal Project Director	187	8840	$86,157	$8,152	Approved
100	1.4	4501	Fabricate, install, and test a two turn RWM coil encompassing Bays A & L.	11/22/2013	1 Director Office of Science	154	8994	$86,311	$7,998	Approved
101	1.8	8250	Additional scope required in Control Account 8250 to prepare/install spacers for the Outer TF flex joints. This work will require the fabrication of 72 unique spacers to connect the OTF flex joints.	11/4/2013	2 Federal Project Director	263	9256	$86,573	$7,736	Approved
102	1.6	6100	In control account 6100 add an additional $13,050 to activity 6100-0049D for an upgraded LEMOPANEL to resource 41 (M&S).	11/14/2013	2 Federal Project Director	17	9274	$86,591	$7,718	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
103	1.1	1305	Add additional task in Control Account 1305 for three (3) additional five gallon kits of CTD 425 are expected to be needed for the VPI of the OH coil	12/2/2013	2 Federal Project Director	31	9304	$86,621	$7,688	Approved
104	1.1	1300	Control Account 1300 requires additional Engineering support through May 2014. This ECP adds additional Engineering/Design Support through May 2014.	12/18/2013	2 Federal Project Director	152	9456	$86,773	$7,536	Approved
105	1.1	1305	In Control Account 1305 add tasks previously identified to baseline. These are tasks identified by the CAM that occur after the OH VPI. They have been shown in the current schedule and EAC for some time.	12/18/2013	2 Federal Project Director	47	9503	$86,820	$7,489	Approved
106	1.1	1200	Control Account 1200 requires additional labor to complete documentation.	1/2/2014	2 Federal Project Director	15	9518	$86,835	$7,474	Approved
107	1.6	6100	In Control Account 6100 it appears as though an error was made when entering information into Primavera from the WAF and the second digit of the budgeted hours was clipped for activity 6100-0073A. A spreadsheet and screenshot from WAF is attached. This ECP corrects the budgeted hours (increased cost).	1/2/2014	2 Federal Project Director	20	9538	$86,855	$7,454	Approved
108			NOT USED				9538	$86,855	$7,454	
109	1.5	5200	DCPS (Control Account 5200) additional scope: Prepare/Install DCPS computer, Halmar Signal Conditioner interface box, Temp. conn. panel, RTC interface chasis, IT and Management Support.	3/11/2014	2 Federal Project Director	286	9824	$87,141	$7,168	Approved
110	1.3	3200	A review of Control Account 3200 (Cooling Water) indicated a budget need. The current unstarted activities will be deleted an replaced by the activities shown on the attached WAF.	3/31/2014	2 Federal Project Director	174	9998	$87,315	$6,994	Approved
111	1.8	8200	In Control Account 8200 delete activity 8200-0110 "Adjust PF Coils". Due to the nature of how work was performed this activity is no longer required to be performed. Add an additional task to Control Account 8200 to remove gaps around the TFOL Al block interface using epoxy. Increase cost due to man hours for this field work.	4/7/2014	2 Federal Project Director	8	10006	$87,323	$6,986	Approved
112	1.2 1.7	2490 7100	Move the baseline start and finish dates for several tasks. In 7100 for ORA Support, and in 2490 move the installation tasks for the reinstall of the IR Camera(s), LOWEUS, and Transmission Grating Spectrometer due unclear path forward.	4/4/2014	3 Project Manager		10006	$87,323	$6,986	Approved
113	1.1	1304	In Control Account 1304 delete activity 1304-1154 "Fab/Deliver supports for OTF jumpers" and replace with new activity capturing the updated cost/schedule for the fabrication and delivery of these parts.	4/7/2014	2 Federal Project Director	212	10218	$87,535	$6,774	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
114	Milestone		Revise PEP Level II milestone "Complete fab & test inner TF/OH coil assembly" from JUNE 2014 TO JULY 2014.	4/30/2014	2 Federal Project Director		10218	$87,535	$6,774	Approved
115	1.1	1300	In Control Account 1300 add additional EA//EM oversight resources for overseeing of the Centerstack fabrication through July 2014.	5/2/2014	2 Federal Project Director	189	10407	$87,724	$6,585	Approved
116	1.1	1306	In Control Account 1306 the subcontract for the fabrication of the three (3) sets of PF coils has been changed to provide and additional $40K (equitable adjustment) plus an additional $20K for the on-time completion of the remaining four (4) coils.	5/8/2014	2 Federal Project Director	120	10527	$87,844	$6,465	Approved
117	1.1	1304 8250	In control Account 1304 Purchase Order PE013500 has been issued for another set of outer TF connectors (lead extensions). In Control Account 8250 tasks 8250-157, 8250-161, 8250-165, and 8250-169 have been replaced by the shorter bakeout activity 8250-165A.	6/11/2014	2 Federal Project Director	124	10651	$87,968	$6,341	Approved
118	1.1	1300	Add new activity in Control Account 1300 to provide Engineering Support through Sept 30, 2014 to support the CS fabrication activities	7/21/2014	2 Federal Project Director	110	10761	$88,078	$6,231	Approved
119	1.6	6100	The current work now includes additional M&S for a genuine real-time control computer, new higher-performance input/output boards, and a complete restructuring of the software architecture to achieve better reliability, improved performance, lower maintenance and future enhancement costs, and integration of DCPS. In addition, it includes a consultant to help recover from the loss of our experienced power supply engineer, who was fluent in both power engineering and specifying software requirements.	9/2/2014	2 Federal Project Director	260	11021	$88,338	$5,971	Approved
120			NOT USED		2 Federal Project Director		11021	$88,338	$5,971	Not yet submitted for Approval
121	1.8	8210 8250 8200	In Control Account 8200 delete activity 8200-0124 "Re-install RF pipes". Crane availability and space availability precludes completion before CD-4. Add Misc. M&S activity to support field work. In Control Account 8250 add activity 8250-1371A "Install OTF flag supports". These activities were not identified in BL. In Control Account 8210 add activity 8210-0013A Installation oversight extends LOE through January for oversight.	8/26/2014	2 Federal Project Director	29	11050	$88,367	$5,942	Approved
122	1.7	7900	In Control Account 7900 delete activity 7900-110 Prepare NBI2 & CS ISTP Test Procedures. ExiSting procedures being used or modified. This activity is unnecessary.	8/26/2014	2 Federal Project Director	-22	11028	$88,345	$5,964	Approved

Appendix F (continued)

Engineering Change Proposal (ECP) log

ECP No.	Impacted WBS Elements	Control Accounts	ECP Title	Approval Date	Change Level	Contingency Draw K	Contingency Draw Cum K	CBB K	Contingency Remaining K	ECP Status
123	1.7	7100	In Control Account 7100 move BL start/finish dates for activity CS7000052 "ORA Support" to Start: 12/8/2014 Finish 12/12/2014.	8/26/2014	3 Project Manager		11028	$88,345	$5,964	Approved
124	1.1	1002	In Control Account 1002 delete activities associated with preparing/installing new Passive Plates in machine. Installation will cause negative impact on first plasma and will not be required during the first year of operations.	9/5/2014	2 Federal Project Director	-71	10957	$88,274	$6,035	Approved
125			NOT USED				10957	$88,274	$6,035	
126	1.2 1.8	2490 8200	All remaining scope in CA 9417-****-2490 and 8200 that are not required to support the CD-4 KPP's shall be charged to CA 1150-****-X890. The following exceptions are required for CD-4: Restore Gas Inj. system, Pressure Gauges, Shutter/TIV Actuators, TF/OH/PF3/PF5 Rogowski Coils, ECH Preionization System	9/5/2014	2 Federal Project Director	-334	10623	$87,940	$6,369	Approved
127	1.7	7200	In Control Account 7200 CSU Management add LOE task for oversight through January 2015.	9/12/2014	2 Federal Project Director	37	10660	$87,977	$6,332	Approved
128	1.7	7300	In Control Account 7300 NB2 Management add LOE task for oversight through December 2014.		3 Project Manager	31	10691	$88,008	$6,301	Not yet submitted for Approval
129	1.7	7100	In Control Account 7100 delete activity CS7000052 "ORA support". This activity will not be required.	8/26/2014	2 Federal Project Director	-111	10580	$87,897	$6,412	Approved
130	1.1	1302 1305	Move activities: 1305-8800A, 1305-8800B, 1305-8800G, 1305-8800H from Control Account 1305 to 1302. These activities are for the U/L crown installs and the bulkhead fittings which were put in the wrong Control Account in a previous ECP.	9/5/2014	3 Project Manager		10580	$87,897	$6,412	Approved
131	1.7	7100	In Control Account 7100 add LOE hours to support Project Management activities through February 2015.	9/15/2014	2 Federal Project Director	403	10982	$88,299	$6,010	Approved
132	1.1	1302	In Control Account 1302 delete activity 1302-1600 "Tear down assembly area". This activity to be performed by NSTXU Operations. Job 1302 may be closed as a result.	11/6/2014	2 Federal Project Director	-55	10928	$88,245	$6,064	Approved
133	1.8	8250	Add the following activities in 8250: 1. Re-machining of TF lead extensions per request of Engineering 2. Health Physics coverage for 8250 tasks	11/6/2014	2 Federal Project Director	344	11272	$88,589	$5,720	Approved
134	1.6	6100	The cancellation of the (WBS5) FCPC Fault Detector project has cancelled (WBS6) planned CAMAC retirement, so this ECP will supplement the remaining CAMAC memory.	11/24/2014	2 Federal Project Director	28	11299	$88,616	$5,693	Approved
135	1.2	2475	Delete the following activities that are not required for NSTXU CD-4 2475-0170D Update Display Software $55,651.20 2475-0136 Protective Plate Interlocks (I/P Pryometer/Cam) $37,033.20 2475-0138 NBOS Station - Installation $29,931.20	3/30/2015	2 Federal Project Director	-123	11177	$88,494	$5,815	Approved
136	1.7 1.8	8250 7100	Add planning packages to cover scope required to recover from NSTXU arc event. A planning package of $100K for Control Account 7100 and $500K for Control Account 8250.	5/28/2015	2 Federal Project Director	600	11777	$89,094	$5,215	Approved

Appendix G

Transition to Operations Plan

NSTX-U Supported by U.S. DEPARTMENT OF ENERGY Office of Science

Transition to Research on NSTX-U

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC

Stefan Gerhardt

Research Staff

Head of Experimental Research Operations

NSTX-U CD-4 Closeout
B-318
September 2nd, 2015

Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Outline

- NSTX-U scientific goals
- NSTX-U CD-4 plasma results
- NSTX-U organization
- Outline of the first experimental campaign

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Outline

- NSTX-U scientific goals ⟵
- NSTX-U CD-4 plasma results
- NSTX-U organization
- Outline of the first experimental campaign

Five Year Plan Described Five Highest Priority Research Goals

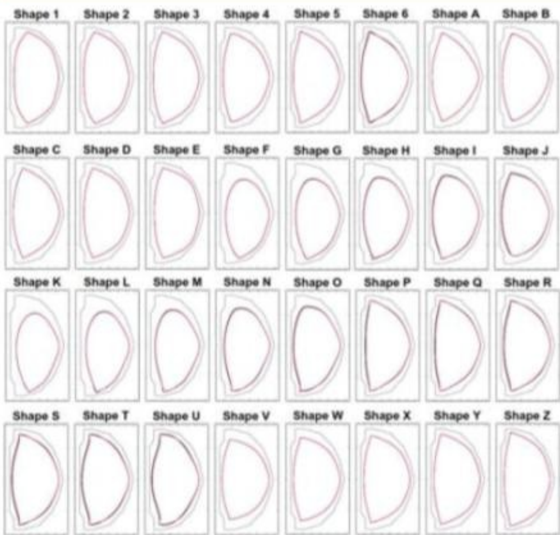
Present Upgrade **Future Upgrade (See Backup Slides)**

1. **Demonstrate 100% non-inductive sustainment at performance that extrapolates to ≥ 1MW/m² neutron wall loading in FNSF**
   - 2nd neutral beam, higher TF
   - Cryopump (future upgrade) , NCC (future upgrade)
2. **Access reduced ν* and high-β combined with ability to vary q and rotation to dramatically extend ST physics understanding**
   - 2nd neutral beam, higher TF, higher I_p
   - Cryopump (future upgrade), NCC (future upgrade)
3. **Develop and understand non-inductive start-up and ramp-up (overdrive) to project to ST-FNSF with small/no solenoid**
   - 2nd neutral beam, higher TF
   - ECH (future upgrade)
4. **Develop and utilize high-flux-expansion "snowflake" divertor and radiative detachment for mitigating very high heat fluxes**
   - Expanded PF-1 coil set, new divertor gas injectors
5. **Begin to assess high-Z PFCs + liquid lithium to develop high-duty-factor integrated PMI solutions for next-steps**
   - Metal PFCs and flowing lithium systems (future upgrades)

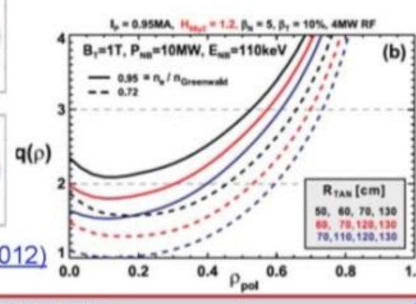
Appendix G

Transition to Operations Plan (continued)

Engineering Design Driven By Physics Considerations



- Poloidal field set consistent with a set of 96 plasma equilibria at 2 MA, 1T.
  - High and low triangularity & elongation, conventional and snowflake divertors, range of OH flux states
  - Defines CS coil locations, power supply requirements, vessel/coil forces/stresses that must be managed, some DCPS limits
- Beam tangency radii determined by integrated modeling with TRANSP.
  - Provides a range of current profiles.



J. E. Menard, et al., Nuclear Fusion **52**, 083015 (2012)

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 5

Long-Term Research Agenda For NSTX-U is Defined in the 5-Year Plan

- Available on the web at:
- http://nstx-u.pppl.gov/five-year-plan/five-year-plan-2014-18
- 11 Chapters, written by the entire NSTX-U team, describing
  - the research goals
  - future upgrades to the facility
- Reviewed over three days in May 2013.
- Accepted by DoE.

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015)

Outline

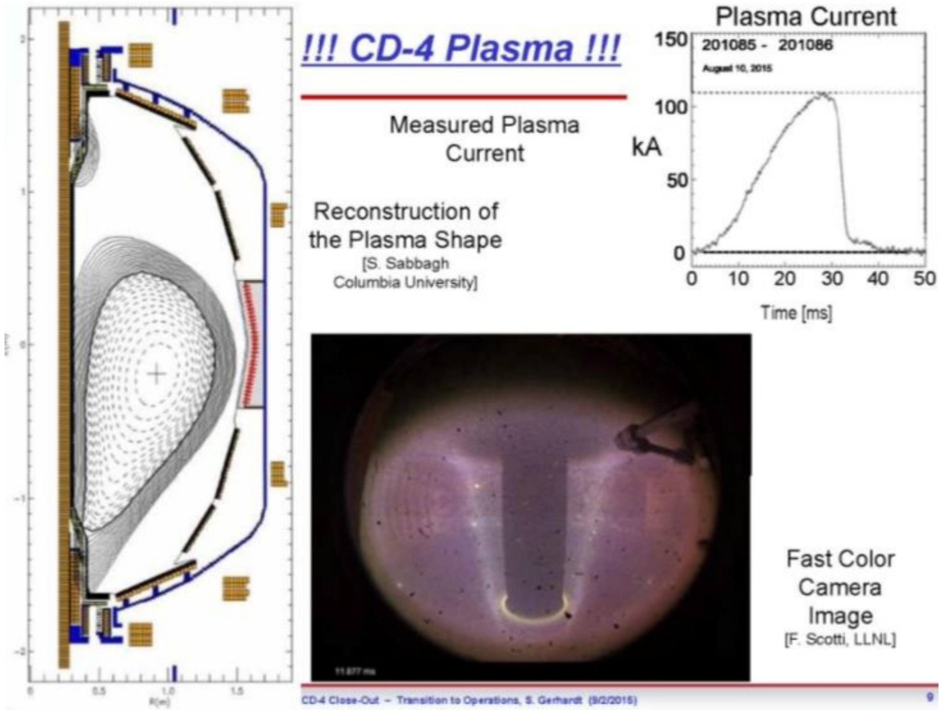
- NSTX-U scientific goals
- NSTX-U CD-4 plasma results ←
- NSTX-U organization
- Outline of the first experimental campaign

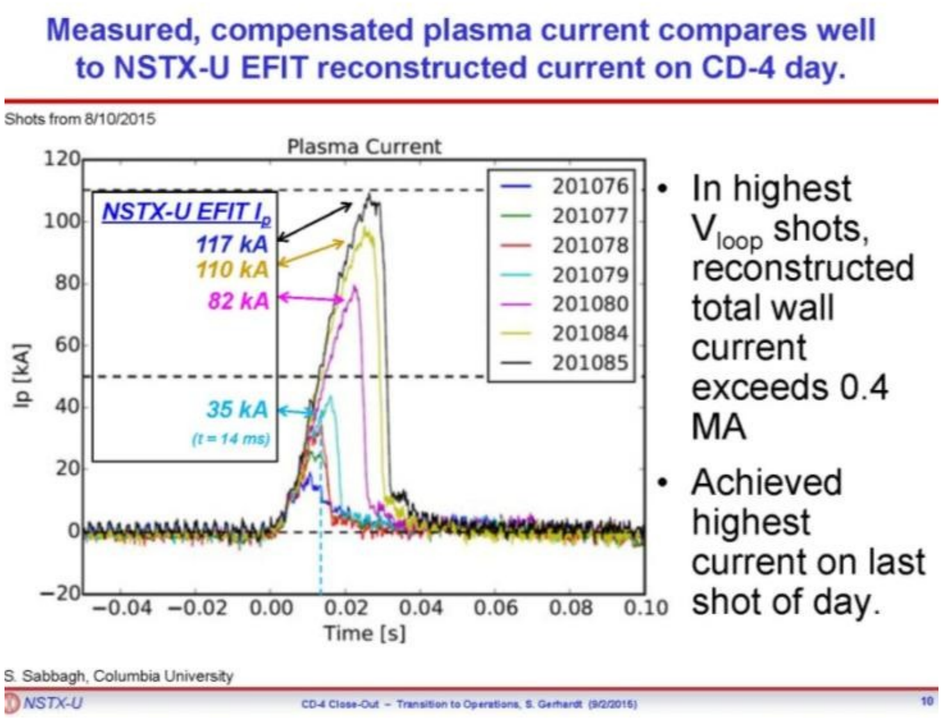
NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 7

CD-4 Run-Up

- [8/3/2015] ES&H Executive Board accepted the ACC recommendation to restart the facility.
- [8/4/2015] Begin the coil system Integrated Systems Test Procedure (ISTP-001)
  - [8/4/2015] Complete Coil High-Pots
  - [8/5/2015-8/7/2015] Single Coil Test Shots
  - [8/10/2015] Combined Field Test Shots
- [8/10/2015] Begin plasma operations under XMP-100.
  - Achieve 100 kA of plasma current
- [8/11/2015 & 8/12/2015] Continued operation on XMP-130.
  - Achieve ~140 kA, improve plasma positioning.

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 8

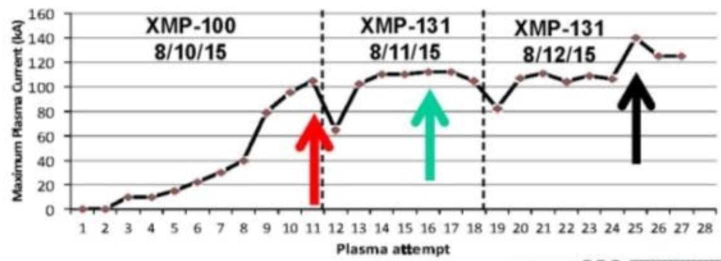

!!! CD-4 Plasma !!!
Measured Plasma Current
Reconstruction of the Plasma Shape
[S. Sabbagh Columbia University]
Plasma Current
201085 - 201086
August 10, 2015
kA
Time [ms]
Fast Color Camera Image
[F. Scotti, LLNL]
CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015)
9


Measured, compensated plasma current compares well to NSTX-U EFIT reconstructed current on CD-4 day.
Shots from 8/10/2015
Plasma Current
NSTX-U EFIT Ip
117 kA
110 kA
82 kA
35 kA
(t = 14 ms)
201076
201077
201078
201079
201080
201084
201085
Ip [kA]
Time [s]
• In highest Vloop shots, reconstructed total wall current exceeds 0.4 MA
• Achieved highest current on last shot of day.
S. Sabbagh, Columbia University
NSTX-U
CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015)
10

Appendix G

Transition to Operations Plan (continued)

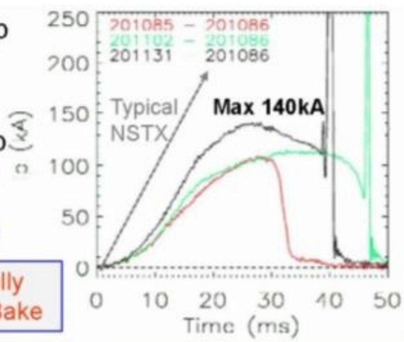
Continued Improvement in Plasma Current and Duration in Sixteen Plasma Shots over 1.5 Days



(27 out of 29 attempts were "good" over 2 days)

(First shot after morning He glow takes a hit)

- Centering plasma and shrinking outer gap lengthened discharge (Tues)
  - Larger PF3/PF5 improves vertical stability
  - Modest improvement in max I_p
- Reducing prefill fueling increased I_p ramp rate (Wed)
  - Increased maximum I_p ~ 135 – 140 kA
  - More importantly, would allow reduction in V_{loop}



Performance Should be Dramatically Better Once We do the Full Vessel Bake

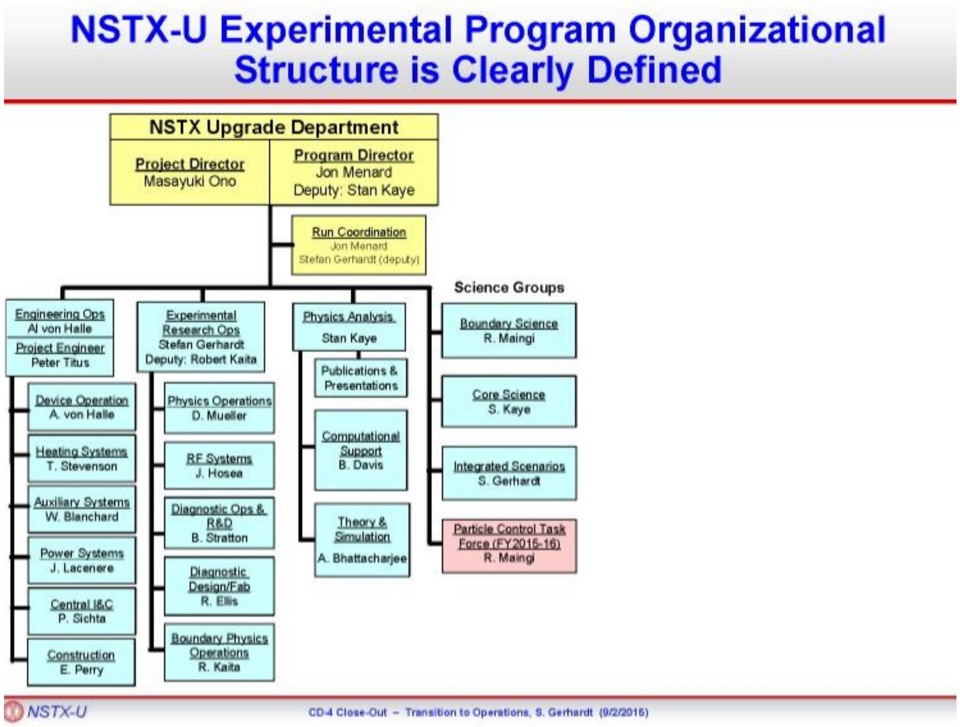
D. Battaglia, PPPL

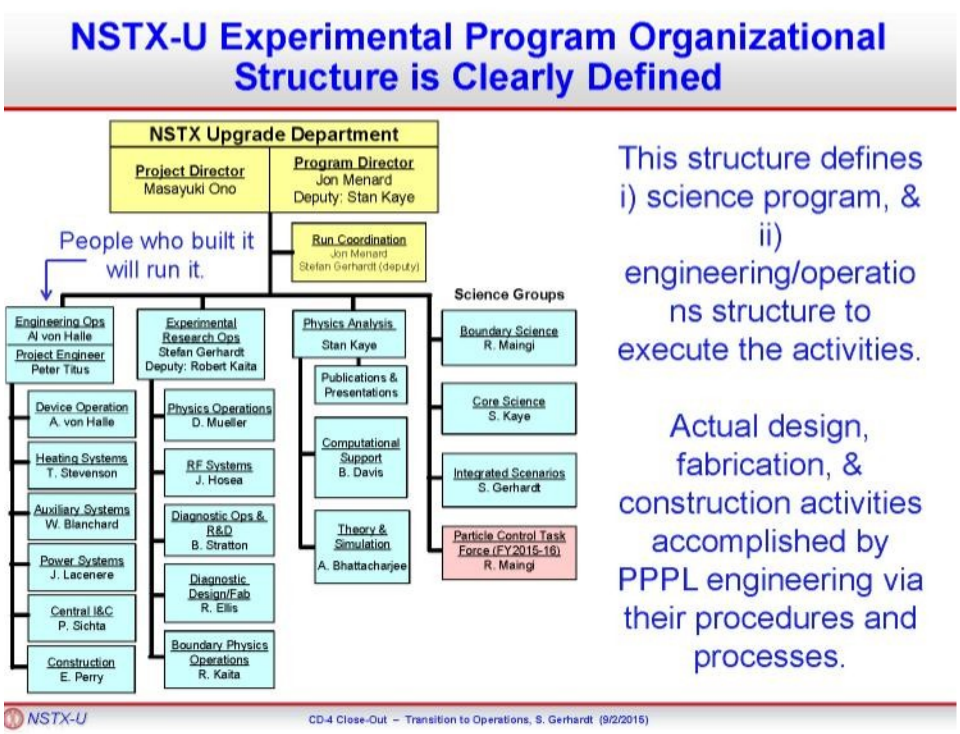
Outline

- NSTX-U scientific goals
- NSTX-U CD-4 plasma results
- NSTX-U organization ⟵
- Outline of the first experimental campaign

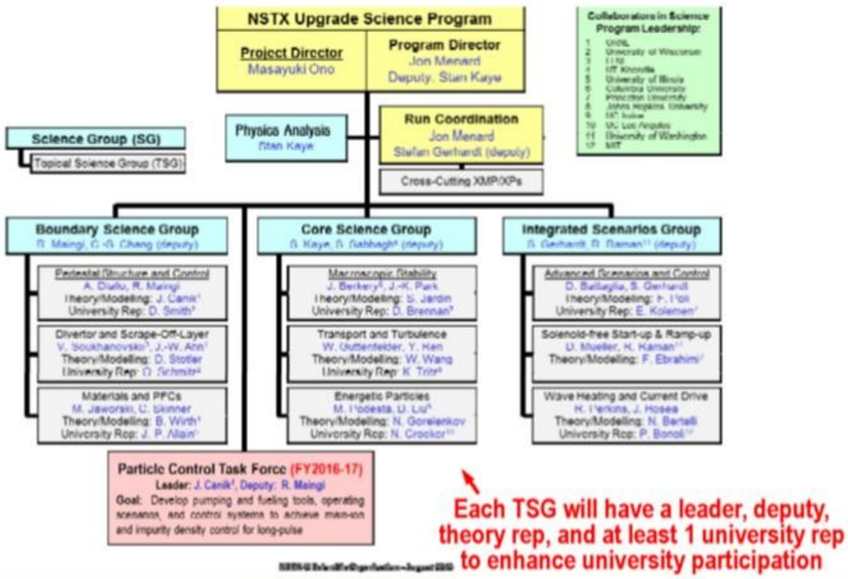
Appendix G

Transition to Operations Plan (continued)





NSTX-U Research Program Is Organized Along 3 "Science Groups" and 9 TSGs for the FY15 run



NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2016)

Many Non-Upgrade Tasks Have Been Undertaken to Prepare for the Run

- Crucial diagnostics
  - Many upgrades to the magnetic diagnostics
  - Large changes to the critical Thomson scattering systems successfully implemented
  - All major profile diagnostics installed and calibrated.
  - Many new or upgraded diagnostics…
- Upgrades to the High Harmonic Fast Wave (HHFW) antenna.
- New boronization systems with improved safety features.
- New plasma control computers and many algorithm upgrades

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Appendix G
Transition to Operations Plan (continued)

Daily Operations Directed by Experimental Proposals (XPs) and Experimental Machine Proposals (XMPs)

XPs

- Describe experiments to answer science questions
- Governed by OP-ADX-03
- Reviewed by
  - topical science group
  - run coordinator
- Typically described 1/2-2 days of machine operations
- Expectation that that each XP will lead to a publishable result

XMPs

- Describe experiments to qualify new machine capabilities
- Governed by OP-ADX-02
- Reviewed by
  - physics operations branch head
  - research operations division head
- Typically describe ½ -1 day of machine operations
- Expectation is that each XMP will facilitate multiple XPs.

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 17

XPs and XMPs Defined at the Research Forum, then Further Refined

- Research Forum was help at PPPL Feb. 24th-27th
  - *127 billion (??)* proposals presented in Topical Science Group and Science Group breakout sessions.
  - Initial prioritizations performed.
  - Initial XP sequencing defined.
- Now in the process of reviewing and finalizing XPs and XMPs.
  - ? XMPs have been approved, ?? more in active development.
  - ?? XPs have been approved.
  - These are sufficient for the first ~2 months of the run campaign

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 18

Appendix G

Transition to Operations Plan (continued)

Outline

- NSTX-U scientific goals
- NSTX-U CD-4 plasma results
- NSTX-U organization
- Outline of the first experimental campaign ⟵

Sequence From CD-4 To Full Research is Well Defined

- Phase 1 Coil Testing ✔
  - Commission TF, OH, PF coil systems required for CD-4.
- CD-4 ✔
- Phase 2 Coil Testing: ✔
  - Do remaining coils for magnetics calibrations
- Small Vent ✔
- MPTS Rayleigh-Raman ✔ Scattering
- Bakeout
- Phase 3 Coil Testing
  - Prepare for Commissioning/Startup Phase
- Commissioning/Startup Phase
- Research Ops
- Phase 4 Coil Testing
  - Increase to full fields for research phase
- Final Research Operations

✔	✔	✔	✔	✔	In Progress	
Phase 1	CD-4	Phase 2	Vent	MPTS	Bakeout	Phase 3
8/4	8/10	8/12	8/17	8/19	8/26	9/30

Startup	Research	Phase 4	Research
10/07			

Appendix G

Transition to Operations Plan (continued)

The NSTX-U Research Program Will Initiated By a Sequence of XMPs

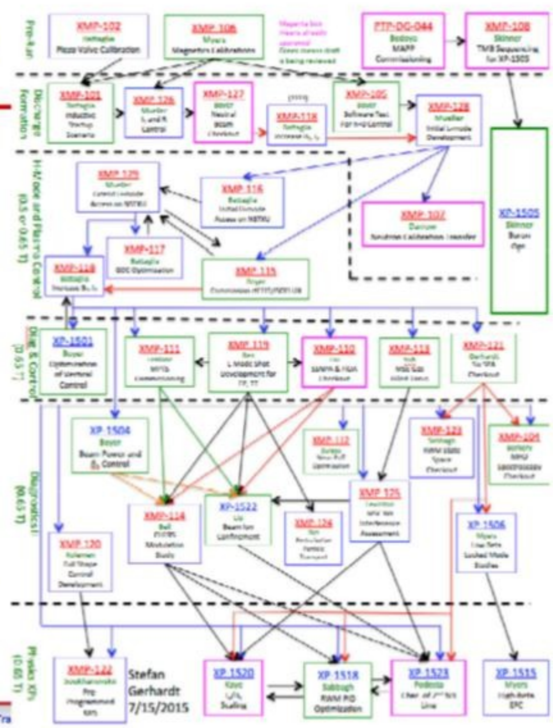
- XMPs for pre-plasma calibrations (3)
- XMPs to reestablish basic "L-mode" plasma operations (7).
- XMPs for "H-mode" access and advanced plasma boundary control (5)
- XMPs for additional control development and initial diagnostic checkout (6)
- XMPs for advanced diagnostic checkout (6)

At the completion of this list, we will be ready to execute the critical XPs (I_P & B_T Scaling, Characterization of the 2nd NB Line)

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 21

The Linkages of the First XMPs and XPs Have Been Defined

- Obviously, not going to discuss this in detail.
- Engineering requirements are consistent with present facility plans.
  - 2 beam boxes
  - Full set of TF, OH, PF coils
    - TF to 0.65 T.
  - 6 SPAs (for RWM coils)
  - Boronization



NSTX-U CD-4 Close-Out – Tra

Appendix G

Transition to Operations Plan (continued)

Physics Operations Staff+Collaborators Will Be Ready to Execute the NSTX-U Research Program

- Three NSTX physics operators will return to NSTX-U.
  - D. Mueller is a world-recognized tokamak driver.
    - Operated TFTR
    - Has collaborated on EAST and K-STAR control development over the last year.
  - D. Battaglia has spent the last 2 years as a DIII-D operator
    - Was responsible for the CD-4 XMPs
  - R. Raman (U. of Washington) provides leadership in CHI, MGI areas + physics operations.
- D. Mueller holding a physics operator course.
  - ½ in July, ½ in September.
  - Plan to train an additional 2-3 physics operators.
  - Slides for course:
    - http://nstx.pppl.gov/DragNDrop/Operations/Physics_Operations_Course/
- Major diagnostics have primary and backup support.

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 23

Summary: NSTX-U is Well on the Way To an Exciting First Run Campaign

- Upgrade was designed to facilitate the research program.
  - And successfully built (Ron's talk).
- The CD-4 plasma activity was very successful.
- The scientific program and management team are in place to develop and exploit the facility.
- The sequence of events leading to research operations is well defined, and we are well along the way.

NSTX-U CD-4 Close-Out – Transition to Operations, S. Gerhardt (9/2/2015) 24

Appendix H

Lessons Learned

LL Number	WBS	Success or Opportunity	Category	Description & Discussion
1	1.5	**O**	Management/Organization	DCPS was a project unto itself and had too many conflicting “cooks” spoiling the soup. The specifications and requirements changed very late in the project after our main FDR. The functional organization stepped in and inappropriately communicated ways yet made key improvements to the requirements. Software was new and made use of new tools and languages not employed at PPPL much before. Teaming among the several branches of the project was very low and communication was at times poor or non-existent except that the COG who was gifted in many areas of this project held it all together. Unfortunately we lost this COG and had to make do. Yet, the effect of this loss on this team was a cautious yet palpable coming together to finish their own scope such that the system arrived on time. The false starts, rework, changes in direction early, and the overall inefficiency cost dollars and clock time but it came together in the end.
2	1.1	**O**	Organization/Staffing	Better balance in assigning CAM's to scope. The centerstack design and fabrication was assigned to one CAM who was the laboratory's expert in coil manufacturing. The work scope should have been distributed to at least 3 CAM's. The failure to do so led to some oversights in procurement inspections, timely reconciliation of cooling wave analysis, more complete field supervision, support of EVMW CAM duties. The Center stack WBS relied heavily on one senior COG who quickly became overloaded. The main bottleneck was for tooling which required a lot of attention. Some earlier support on engineering the tooling might have helped save some rework.
3	All	**O**	Resources	Earlier recognition of the need for an independent QC receipt inspector. During the last 20 years PPPL has reacted to budget challenges by reducing overhead cost (and staff) by transferring work scope to directly funded project staff. One of the positions eliminated was a full time QC receipt inspector whose responsibilities were transferred to the project procurement technical representative (CAM in most cases). Mid way through the project it became apparent that hardware deliveries for non critical, small hardware (at the time) did not receive timely and complete inspections. The project requested, and PPPL agreed to hire a QC inspector which offloaded the CAM's..

LL Number	WBS	Success or Opportunity	Category	Description & Discussion
4	ALL	**O**	Procurement	Causal Analysis – Vendor "X", Inc. February 2/8/2013. (Detailed report available upon request) Multiple awards (6) to a new, unknown supplier for NSTX/U components resulted in unacceptable quality, rework, and/or re-award of contracts, all of which resulted in a delay in schedule for the project and additional costs. After award, one of the work activities covered by these six awards became part of the critical path and, as a result, had a significant impact on the schedule. As a result, PPPL initiated an analysis to identify the causal factors so that actions can be taken to prevent this from recurring. The root cause identified was the evaluation and oversight of the vendor was inadequate. Contributory causes were: A. Inadequate incoming inspections and supplier oversight due to lack of appropriate resources assigned to these procurements. B. Inadequate hold points/first article inspections for jobs requiring weld preparation. Recommendations include; 1. Develop a process for the evaluation and oversight of new and unknown fabrication suppliers until adequate confidence is achieved. Such a process should consider financial stability, types of contracts to be awarded to this supplier, time frames of the contracts, performance parameters, risks associated with work to be done, references, timely feedback from first wards, etc 2. Insure adequate staff for the timely inspection of hardware and components. 3. Insure hold points/first article inspections, which are especially important for vacuum welds or other welds with high loads.
5	All	**O**	Resources	Key pacing resources like welding required careful handling and often became pinch points. Veteran welders were in high demand throughout the project. The PPPL Tech Shop work order system was well managed and the Work Control Center (WCC) did an outstanding job applying timely use but early training of welders in anticipation of this peak need might have eased project problems.
6	ALL	**O**	Testing	Insufficient time was budgeted for testing. The troubleshooting time always takes more than expected and should be included in future estimating considerations.
7	1.7	**O**	Management/Organization	Number of Project reviews. The time spent in preparing for, conducting and follow-up from both PPPL and DOE initiated reviews was under estimated. This project conducted 34 high level reviews that utilized over 72 externals reviewers from 22 institutions. While somewhat beneficial, impacts to project cost, schedule, and resources should be more adequately budgeted.

LL Number	WBS	Success or Opportunity	Category	Description & Discussion
8	1.7	**O**	Resources	Sharing the analysis engineers with the ITER project led to delays in the completion of calculations. This led to late receipt of drawings and subsequent late delivery of materials/components to the field. This required the project plans to be adjusted on a weekly basis which resulted in cost inefficiencies. While this did not impact critical paths tasks it did impact the cost and schedule for machine assembly (i.e. structural supports).
9	1.7	**O**	Policy/Procedures	Institutional overtime policy led to lost scheduling opportunities during those weeks that included holidays. Holidays were not counted toward the 40 hour work week calculation for premium time hence staff were not inclined to work overtime. The project schedule could have been shorten by an estimated 20 work days.
10	ALL	**O**	Design	Consider better management of design tolerances. Be surgical in requiring small tolerances. This will drive the vendor’s procurement cost, require extensive in-house engineering time to disposition nonconformance reports (NCR's), and increase assembly time. The impact manifests itself in both increased cost and schedule stretch-out. This has been a chronic challenge on projects at PPPL. 'Better is the enemy of good enough"
11	1.1	**O**	Design	PPPL calculation documentation was complete and accurate but lacked clear and definitive conclusions and summaries. This led to misunderstandings and time wasted in completing designs/drawings. Crisp conclusions and design direction needs to be included in the final closing statements.
12	1.1 and 1.5	**O**	Resources	Personnel single point failures has led to schedule impacts when critical people were not available (due to prolonged illnesses and deaths). These could not have been anticipated but for projects spanning long periods of time they are likely to occur and should be factored into cost and schedule contingencies. Also, critical corporate skills should be identified with backup people assigned to be mentored.

LL Number	WBS	Success or Opportunity	Category	Description & Discussion
13	ALL	**O**	Estimating	Under estimates of several skills manifested itself into resource shortages and schedule delays. The work estimating procedure should be revised to require supervisors of the skill organizations (i.e. welding, machining, field crew installation, drafting etc.) to review and provide input to all work estimates. Furthermore, technician supervisors should be required to attend design reviews to better promote value engineering. At the very least ensure early on that what is designed can be built.
14	1.1	**O**	Design	Some of the components designed for this project did not take as-built field conditions into consideration**.** Accurately manufactured parts required re-work before they could be assembled to components that did not match the NSTX CAD model. **Recommendation**: Individuals responsible for the design should engage with the field (inspect/measure the field condition and speak with operations people) to ensure that the designs for new components integrate into the imperfect, as-built conditions that actually exist.
15	All	**O**	Policy/Procedures	Establish a policy for field installations – when does a review have to be completed of field design. Develop field installation policy; Revise WP procedures accordingly
16	All	**O**	Policy/Procedures	Clarify existing Design review procedures to ensure all applicable subject matters experts are represented. The PPPL Design Review Process needs to be comprehensive, cover all important aspects or components of a work activity, and include all technical disciplines involved in the work activity. A broader review of the PPPL Design Review Process should be performed post CD--4 as part of CAP25---75(IER).
17	All	**O**	Management/Organization	Ensure that a full time dedicated project engineer actively oversees the design process. The project had to "share" an experienced individual which had cost and schedule implications.
18	All	**O**	Policy/Procedures	PPPL needs a rigorous process to ensure that each component or system is assigned to a clearly identified individual who is aware of its current and ongoing status and history, and is someone who is both capable and responsible for its technical aspects. A broader review of the PPPL use of SME's should be performed post CD--4 as part of CAP25--75(IER).

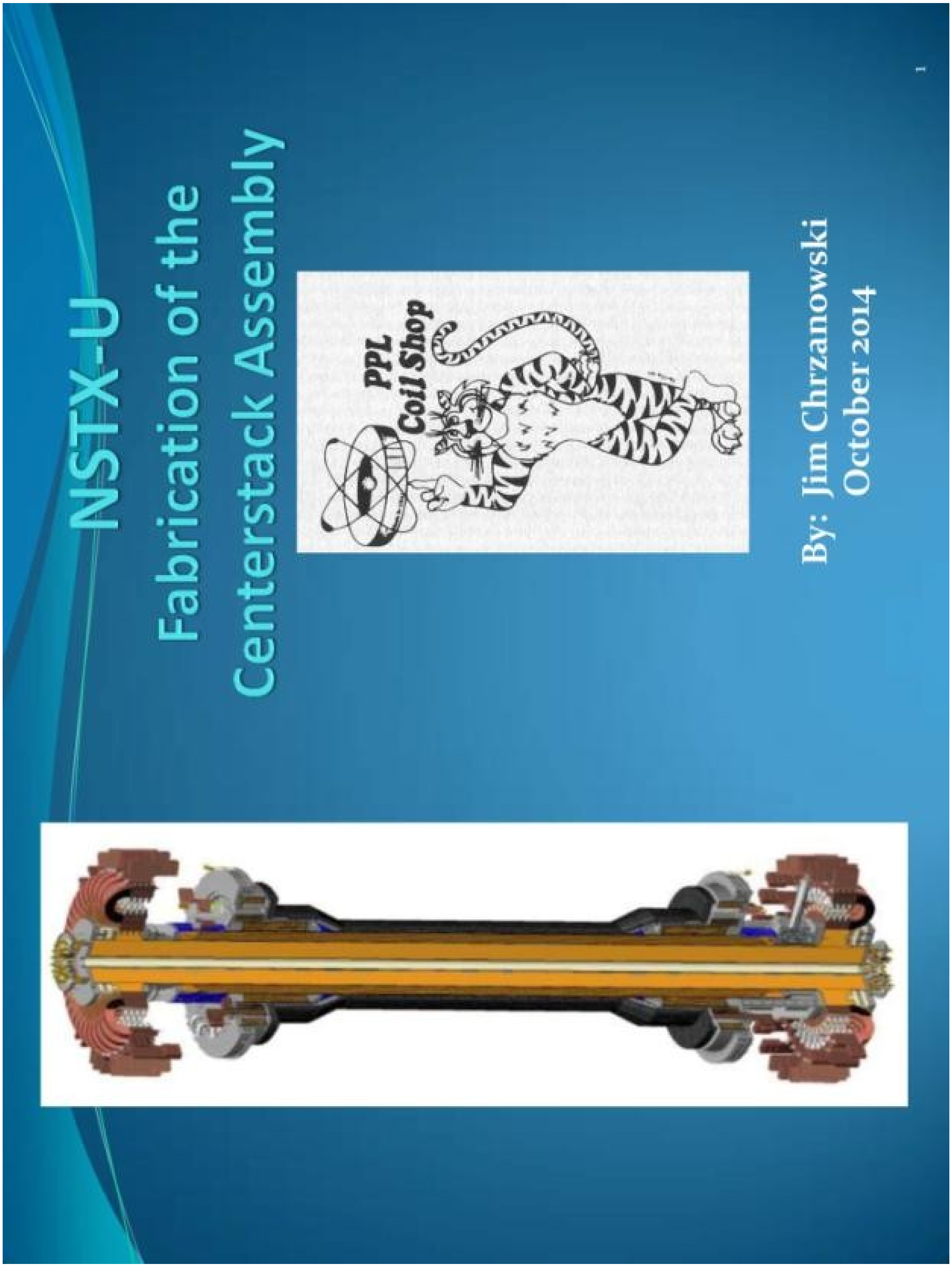
LL Number	WBS	Success or Opportunity	Category	Description & Discussion
19	All	**O**	Policy/Procedures	During the design phase and after the FDR, the project needs to ensure that the review process extends to as---built configurations including field changes.
20	All	**O**	Policy/Procedures	Rigid adherence to established engineering procdures to prevent inadvertent installation errors.
21	1.1	**O**	Design	We spent too much conceptual mechanical engineering design and analysis time trying to meet the GRD full power supply recommendations and eventually had to punt and do DCPS. Recommendation would be to craft the GRD more carefully or consider ramifications sooner. CDR was extreme. For example, GRD shot spec was also over the top. 60000 full power shots eventually became 20000 shots total, 2000 full power on OH with 6000 full power plasmas. Chewed up a lot of analysis and fatigue allowables.
22	1.7	**O**	Management/Organization	KPP development. The PEP section 2 on KPPs wshould have been more concise. This led to many conversations about what was required to meet the KPPs and project completion. There were several meetings where the demonstrated performance activities were treated as "design points", when they are far below NSTX performance criteria; definitely below NSTX-U design capabilities. Additionally, [illegible]
23	1.2	**O**	Resources	On beams we had some trouble with jobs taking too long. We had some new people and bringing the crew up to speed took a lot of hard work and training. In the end though not only did we build a new beam we built a new Beam Team too.
24	ALL	**O**	Procurement	Ensure that supplier fabrication contracts are awarded based on best value and not best price. More thoroughly vet suppliers qualifications.
25	ALL	**O**	Fabrication of components.	We were burned more that once when the vendor chosen to fabricate our components did not possess the capability to perform the job correctly. **Recommendation**: we establish criteria for matching vendor capabilities to fabrication complexity. See "Procurement Lessons Learned Causal Analysis Report" under review documents.

LL Number	WBS	Success or Opportunity	Category	Description & Discussion
26	1.1	**O**	Coil Molds	TF Inner bundle molds with too tight-fitting around copper. Imperfect molds and imperfect copper bars resulted in quadrant and ultimately full bundle to be larger diameter than designed. This resulted in modifications to many of the parts that interfaced to the coil's over-sized diameters and also resulted in the misaligned TF connector faces. The only factor that allowed the coil to fit into the case was the fact that we had thicker ground layer around the TF Inner bundle and the OH coil. The compliance of the ground layers allowed us to "squeeze" the TF and OH coils into their molds. Conversely, if we did not have a generous ground layer we might not have been able to get the TF and OH into their molds. **Recommendation:** If we had more fiberglass on the individual TF legs, we could have built quadrants much closer to the design dimensions.
27	1.1	**O**	Coil VPI	Plan to sand off resin rich areas from coils that VPI'd in hard molds. Allocate sufficient time in the schedule and cost estimate. Epoxy typically cures at ~100 centigrade, a temperature at which the mold had expanded, resulting with coils that have larger than nominal dimensions.
28	1.4	**O**	Estimating	An accurate global as-built model was not available at the start of design. This led to much field rework when CADD designed hardware was attempt to be fit up to the actual machine. Suggest performing detail metrology measurements and updating CADD models as a first step in the design process.
29	ALL	**S**	Safety	The attention to worker safety resulted in only 6 reportable minor injuries in over 573,000 hours worked. While we have a robust safety organization and up front Management buy-in, it came down to people not taking risks or short cuts in the name of schedule or cost. The safety culture at PPPL is one of its strongest assets.

LL Number	WBS	Success or Opportunity	Category	Description & Discussion
30	1.7	**S**	Supervision	Work control center again provide real value in establishing daily communication of field activities. Support needs (QC weld inspections, Safety support for walk downs, Health Physics) were determined in this daily 10 minute meeting. This process was established during the TFTR D&D project which was successful in finishing safely on schedule and $3.6M under budget.
31	1.7	**S**	Scope	Be clearer in establishing project scope by establishing clear "fences" around the project scope. Define what's excluded as well as what's included. Also, document potential scope contingency as part of the CD-2 baselining requirement. The project benefited by establishing scope contingency source terms some of which was utilized (and documented) which save time and money.
32	1.7	**S**	EVMS	**EVMS the good;** monthly statusing methodology adopted, CPR reports, change control mandated good discipline. **EVMS an Opportunity;** However, the requirement for written variance analysis reports provide little value to the project management office. Causes of cost and schedule variances were discussed real time during the formal monthly status meeting. Staffing issues that drove schedule slippages were resolved many times by the PPPL engineering division and department heads that were in attendance.
33	All	**S**	Policy/Procedures	Adherence to PPPL engineering procedures eng-033 provided discipline in the design process. However, the project provided additional requirements that; 1) provided for tracking and QA verification of design review chits and 2) Required calculations to be signed by the cog engineer whom was the ultimate customer
34	1.7	**S**	Management /Organization	Project was very well organized from the beginning. We have an excellent, very strong project team. We had excellent project initiation, requirements were well defined if over the top here and there, and the work planning and WAFs were outstanding. Project Controls went very well. Project status and EVMS went nearly flawlessly. We were very well supported by the NSTX program as well (Masa and Jon as well as Stefan)
35	ALL	**O**	General	On April 24, PPPL ESU responded to alarms from the NSTX-U experimental area. An active water leak from NSTX-U was observed. Staff discovered that several of the Ohmic Heating coils external cooling paths were damaged at the top end of the OH coil. Additionally, indications of electrical arcing were observed in the vicinity of the water leaks. Initial inspection showed no damage to the OH or other coil systems. The water was secured and investigation into the cause was initiated. As a result of this event, the Laboratory has commissioned a number of reviews to evaluate the cause, determine what actions are necessary to repair the coil, what actions are necessary to improve processes and prevent recurrence. The following teams were commissioned: An Internal Independent Review team, an Extent of Condition Review Team, an Independent External Review Team, and formal Root Cause Analysis Team. Lessons learned relative to deisgn and construction are incorportaed in the above lessons learned. Additionally, since many findings and corrective actions were related to conduct of operations and machine operation, the entire corrective action report is included in its entirety in Appendix O.

Appendix I

Centerstack Fabrication and Assembly



Prelude

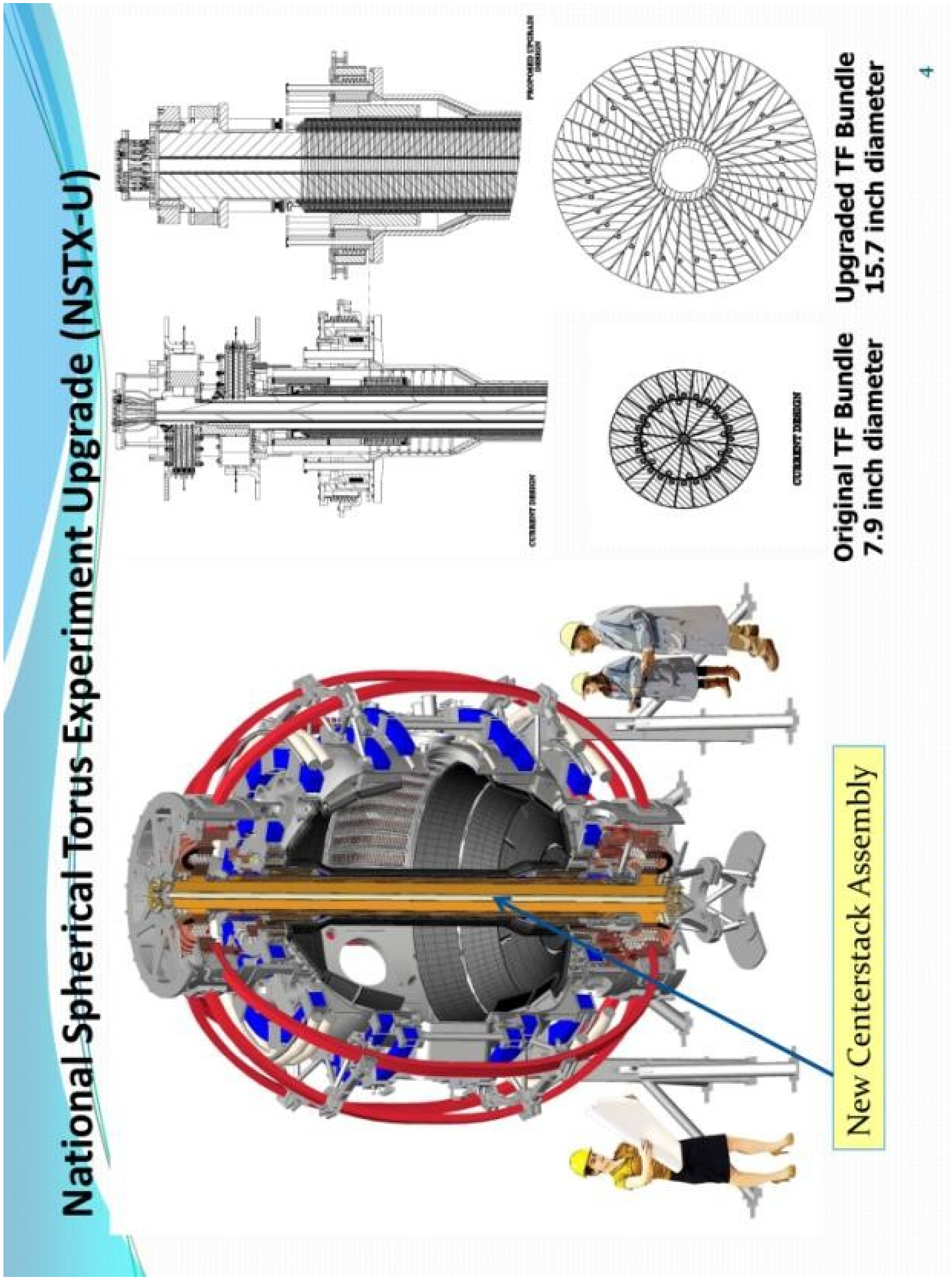
- *This document provides a general overview of the manufacturing and assembly steps that were necessary to complete the Centerstack Assembly for the NSTX-U project.*

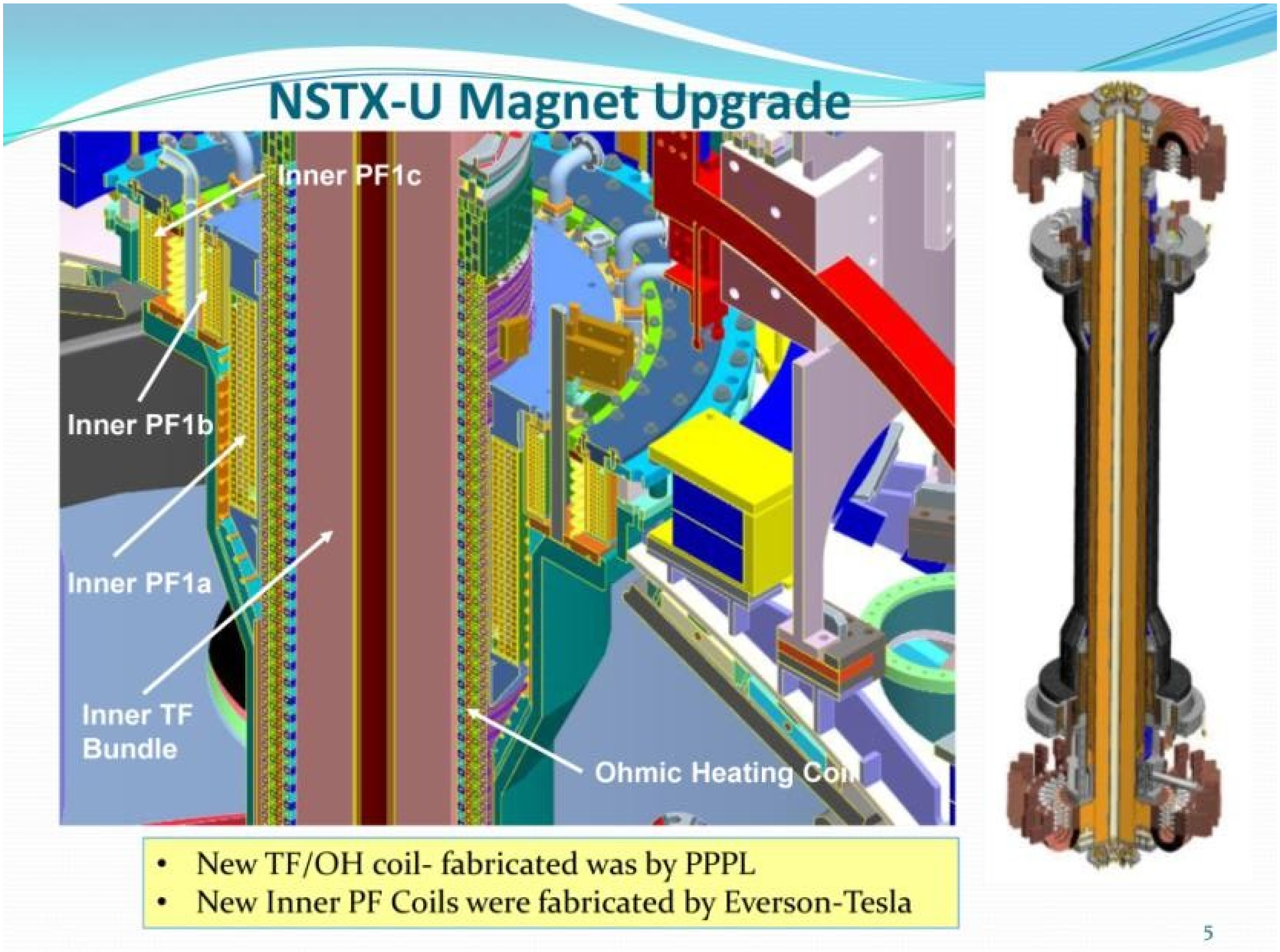
2

Introduction

- In 2009 the US Department of Energy approved the initiation of a project to update the NSTX for approved performance. A new Centerstack was included as part of the upgrade activities. The CS assembly includes:
  - Inner TF Bundle
  - Ohmic Heating Coil
  - Inner Poloidal Field Coils
  - Centerstack Casing
  - Plasma Facing Components

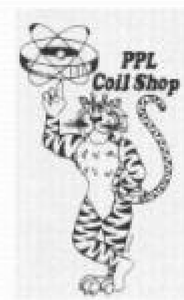
3


National Spherical Torus Experiment Upgrade (NSTX-U)
New Centerstack Assembly
CURRENT DESIGN
PROPOSED UPGRADE DESIGN
CURRENT DESIGN
Original TF Bundle
7.9 inch diameter
Upgraded TF Bundle
15.7 inch diameter
4


NSTX-U Magnet Upgrade
Inner PF1c
Inner PF1b
Inner PF1a
Inner TF Bundle
Ohmic Heating Coil
• New TF/OH coil- fabricated was by PPPL
• New Inner PF Coils were fabricated by Everson-Tesla
5

Inner TF Bundle

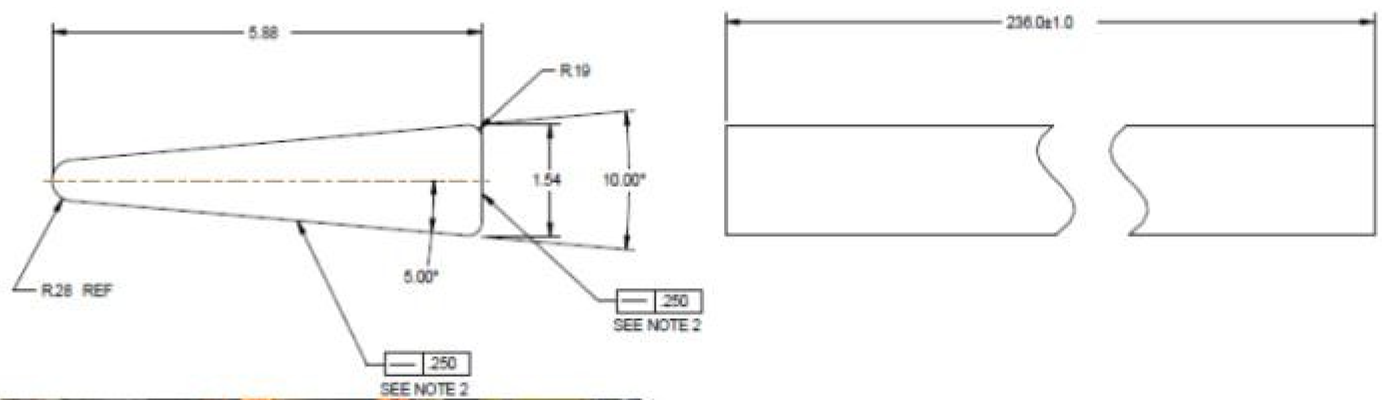
- **General Description:** The Inner TF bundle is a thirty six (36) turn copper coil bundle that forms the inner legs of the Toroidal field coil system. The coil is constructed using pie shaped oxygen-free silver-bearing copper conductors that are, sandblasted, primed and insulated with multiple half-lapped layers of S2 glass tape. Each conductor end has (CDA18150) Copper-Chromium-Zirconium lead extensions that were added via a friction stir welding [FSW] process. The coil was constructed into quadrants that allowed better dimensional control. Each quadrant of (9) conductors were epoxy impregnated using CTD-425 a 2-part system with Epoxy (EP) and Cyanate Ester (CE) catalyst in Part A and Cyanate Ester (CE) in Part B. The finished quadrants were then over wrapped with multiple half-lapped layers of S-2 glass insulation to form the outer ground-wall. The entire insulated coil was then epoxy impregnated using the CTD-425 system.



6

Inner Toroidal Field Conductors

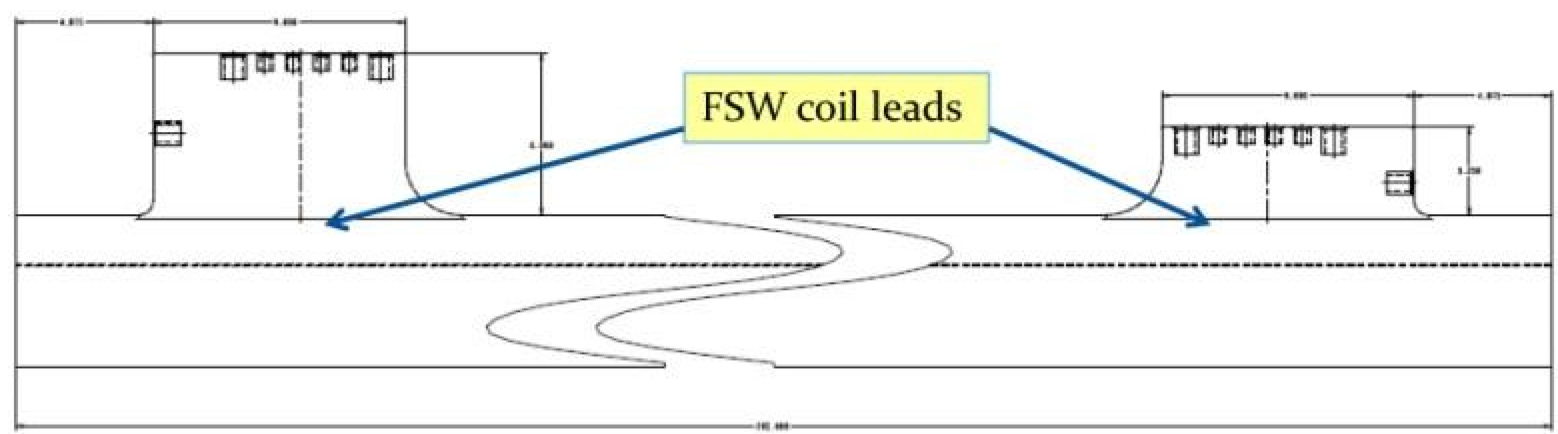
- Inner TF copper extrusions were procured from Luvata-Pori, Finland
- Oxygen-free silver-bearing copper CDA10700



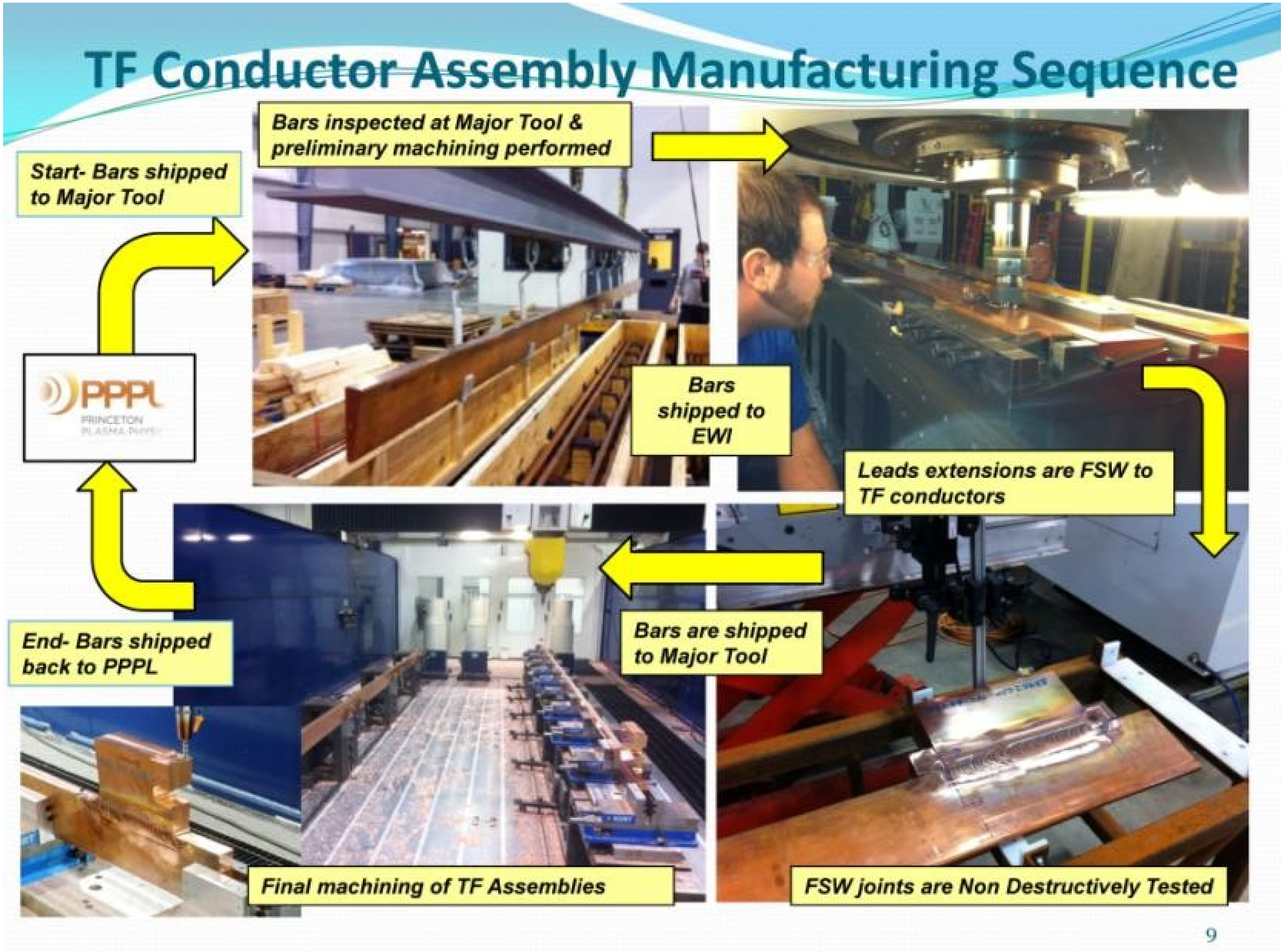
7

Inner Toroidal Field Conductor Assemblies

- The contract for manufacturing the Inner TF conductor assemblies was awarded to Major Tool located in Indianapolis
- The manufacturing was a (3) step process.
  - Initial machining by Major Tool
  - Friction Stir Welding (FSW) of the coil leads to the TF conductor was sub-contracted to Edison Welding Institute, located in Columbus, Ohio.
  - Final machining of the completed conductor was then performed by Major Tool



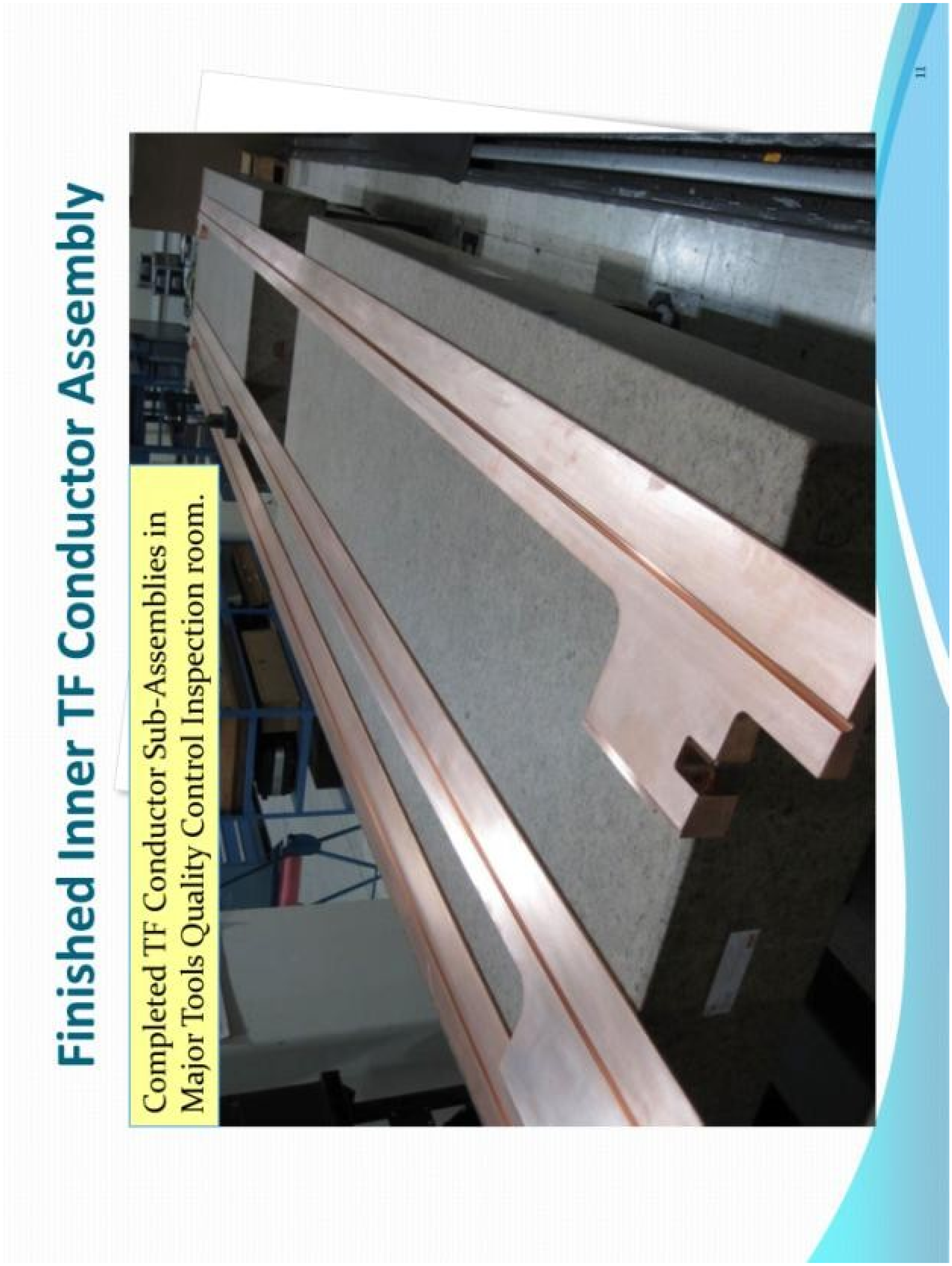
8


TF Conductor Assembly Manufacturing Sequence
Start- Bars shipped to Major Tool
Bars inspected at Major Tool & preliminary machining performed
Bars shipped to EWI
Leads extensions are FSW to TF conductors
FSW joints are Non Destructively Tested
Bars are shipped to Major Tool
Final machining of TF Assemblies
End- Bars shipped back to PPPL
PPPL
PRINCETON
9

TF Conductor Friction Stir Welding

High strength coil leads, Copper-Chromium-Zirconium (CDA18150) were added to each end of the oxygen free silver-bearing copper conductors (CDA10700) by a process known as friction stir welding (FSW). This work was completed by Edison Welding Institute (EWI) in Columbus, Ohio

10


Finished Inner TF Conductor Assembly
Completed TF Conductor Sub-Assemblies in Major Tools Quality Control Inspection room.
11


Delivery of TF Conductor Assemblies
The finished TF Conductors were delivered to PPPL via truck from Major Tool located in Indianapolis, Indiana
12

Soldering Operation

The copper cooling tubes were soldered into the TF conductor assemblies using Solder paste- 96.5 Sn /3.5 Ag w/ GMS based "R" flux *[Glyceryl Mono-stearate, Terigitol (a detergent) and Cyclohexlamine Hydro-bromide]*

13

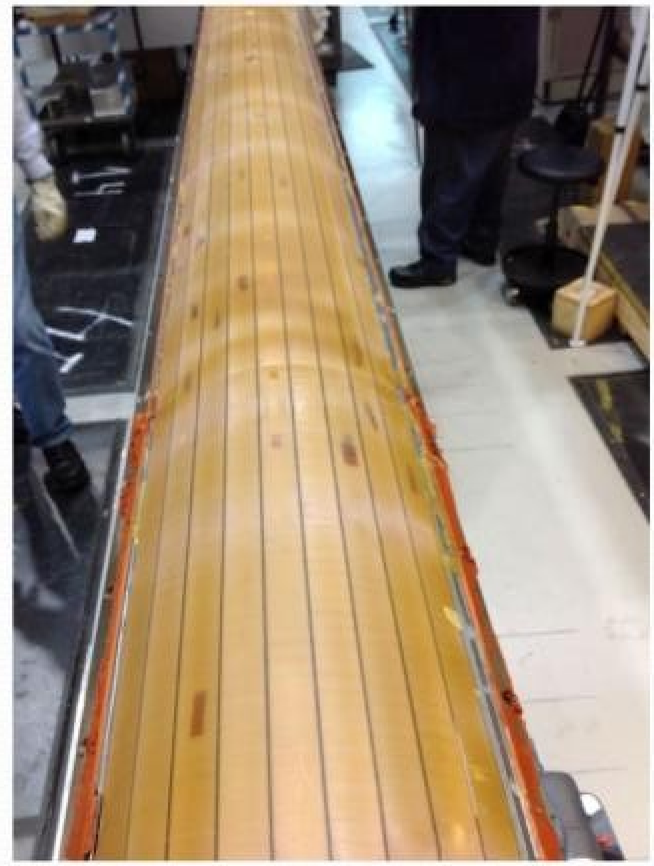

TF Conductor Preparation
Conductors were Post Solder Baked to 170° C to remove any excess flux
Grit blast conductors
Prime conductors w/CTD-450 primer & Cured


Applying S-2 Glass TF Turn Insulation
15


Assembly of Inner TF Quadrants
Assemble (9) individual conductors into each Quadrant mold
16

Assembly of Inner TF Quadrants

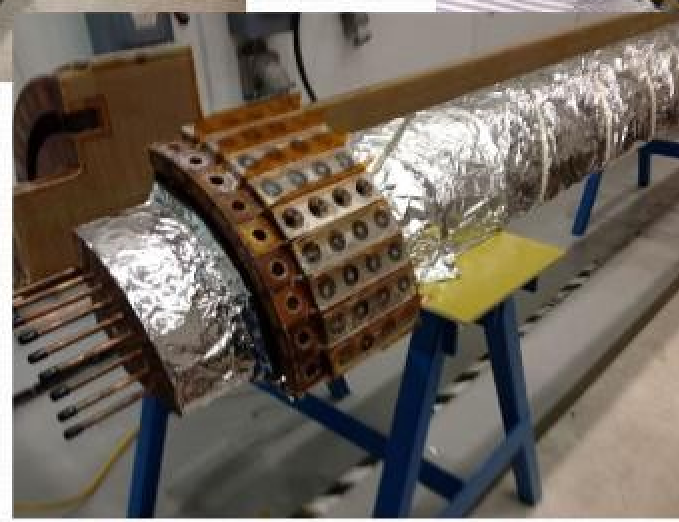
- Once the conductors were assembled into the mold, each TF Quadrant was successfully Vacuum Pressure Impregnated (VPI) using CTD-425 epoxy system



17

TF Quadrant Electrical Tests

- Each of the (4) TF Quadrants successfully pasted their electrical acceptance tests.



18


Completion of First TF Quadrant
19

Assembly of Full TF Bundle

- The four VPI's quadrants were then assembled together to complete the full bundle.

The quadrants will be assembled w/ S-2 between layers & pre-insulated G-10 core

The full TF bundle is Ground wrapped with S-2 glass tape

The full TF bundle is placed into a mold and VPI'd

20


Full TF Bundle VPI'd
Full TF Bundle after VPI
Full TF Bundle in oven and ready for VPI
21


Full TF Bundle Electrical Tests
The Full TF Bundle successfully pasted its electrical acceptance tests.
22

Raising the Full TF Bundle

- Following testing, the Inner TF Bundle was transported to the vertical positioning fixture.
- The TF Bundle was raised to the vertical position in preparation for the application of the Aquapour.

23

Installation of Aquapour Layer

- Installation of Aquapour layer was successfully completed

"Aquapour" is used as a temporary spacer that will be used to maintain 0.100 inch gap between the TF OD and OH ID surfaces. It is removed post VPI of OH coil

24

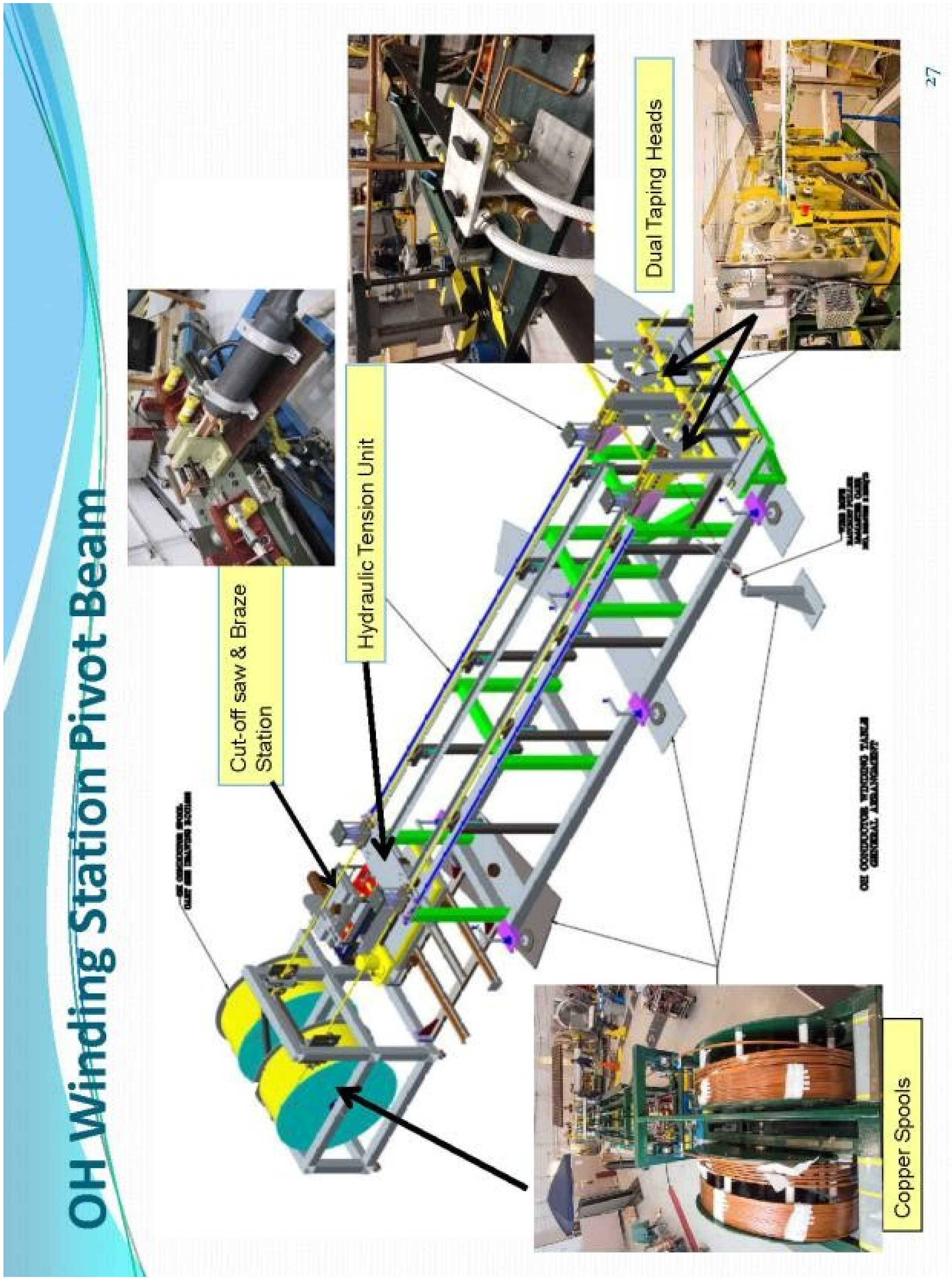

OH Winding Preparations
OH support structure was installed
Epoxy/glass layer was applied over the Aquapour surface to provide a solid winding surface
25

Transfer TF to OH Winding Station

- The TF bundle was transferred to the OH Winding station

Applying Inner ground wrap insulation

26


OH Winding Station Pivot Beam
Cut-off saw & Braze Station
Hydraulic Tension Unit
Dual Taping Heads
Copper Spools
27

Ohmic Heating Solenoid

- **General Description:** The Ohmic Heating (OH) solenoid is a 4-layer [884 turn] copper coil. The coil was constructed using extruded oxygen-free silver-bearing copper conductor w/cooling hole. The conductor is first grit blasted and primed, similar to the TF conductors. Individual turns were insulated with co-wound glass/Kapton insulation applied in multiple half-lapped layers. The OH solenoid conductor was wound (2-in-hand) over the outside diameter of the inner TF coil bundle. A 0.100 inch gap was maintained between the OD of the TF bundle and the ID of the OH solenoid to allow for thermal growth of the components. S-2 glass ground-wrap was then applied over the finished wound coil. The entire wound coil was then epoxy impregnated using CTD-425 system a 2-part system with Epoxy (EP) and Cyanate Ester (CE) catalyst in Part A and Cyanate Ester (CE) in Part B.

PPL Coil Shop

28


OH Coil Lead & cooling fittings were Torch Brazed to OH Conductor
29

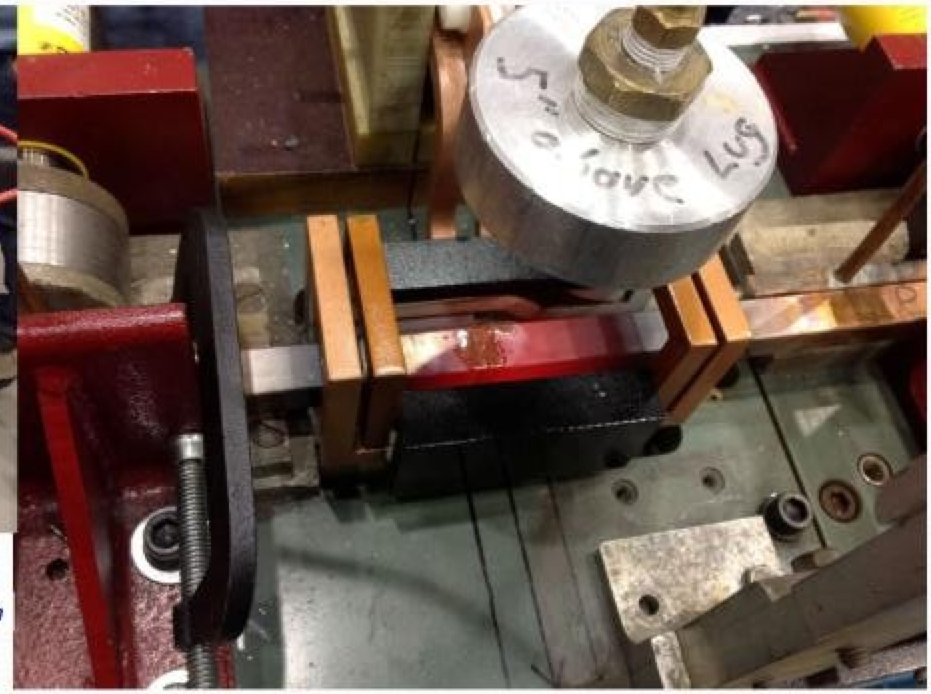

OH Winding Station
OH primed Conductor
30

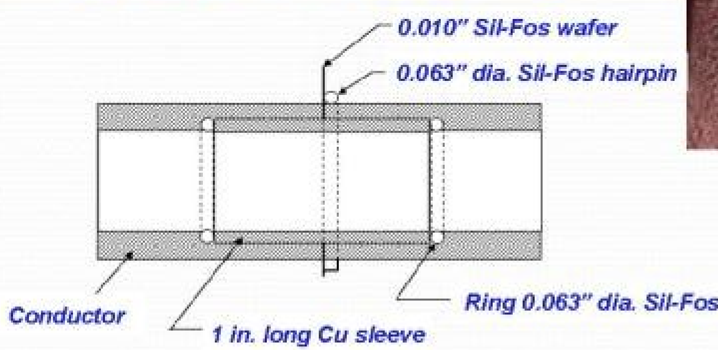

Coil Winding Activities
31


Coil Winding Photos -continued
Photos of some of the winding activities and personnel
32

OH In-Line Brazing

- (32) in line brazes were performed during the OH winding operations.
- Each braze joint was mechanically loaded (stretched) and helium leak tested to ensure a quality braze joint.

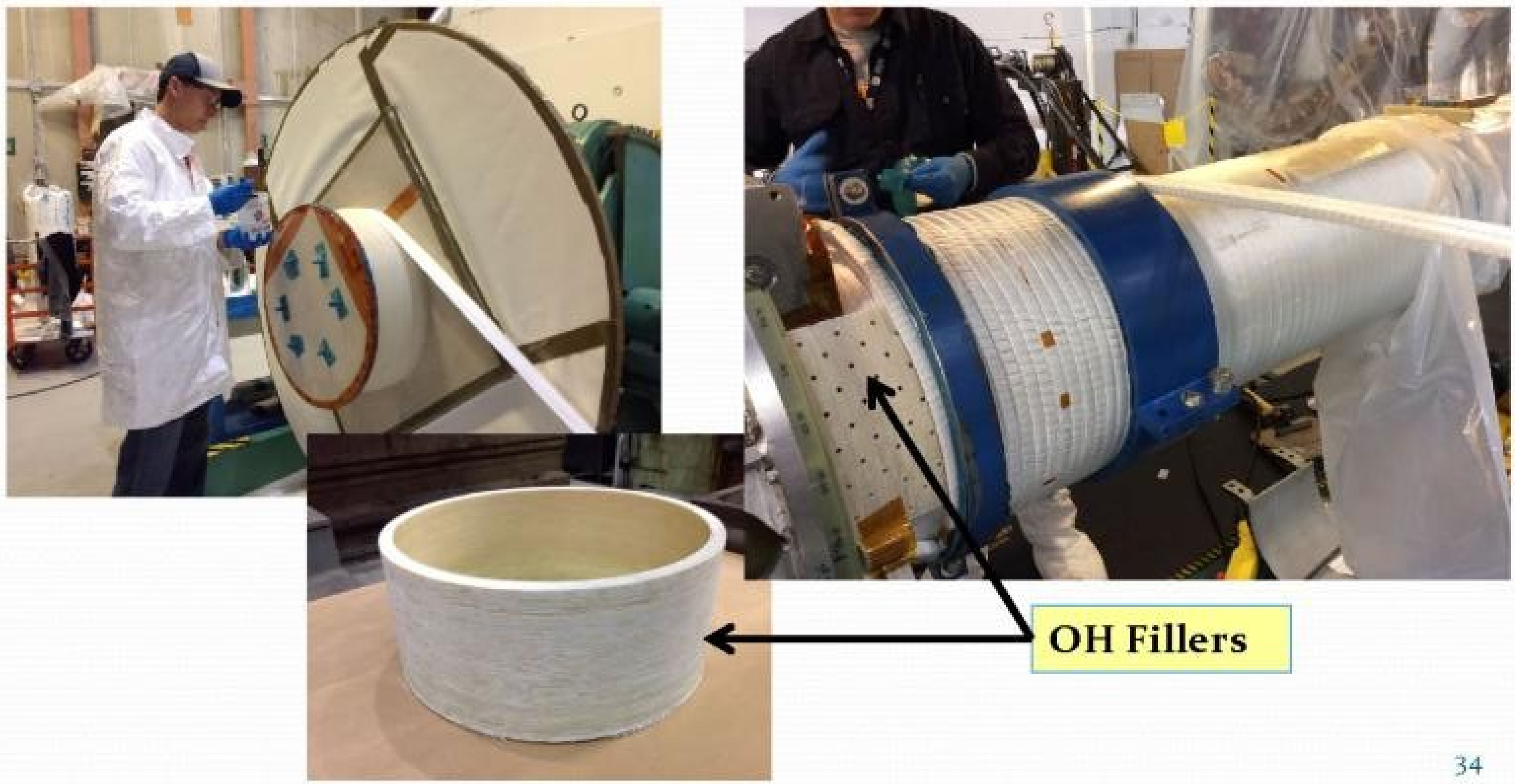




33

OH Coil Fillers

- The OH insulating fillers located at each end of the OH coil were fabricated in-house using a wet layup process with glass tape and CTD-425 resin system.
- The cured fillers were then machined and cut to fit the layer to layer transition areas



34


Completion of Coil Winding- OH Winding Team
Most of the OH coil winding team members
35

Ground-wrapping OH Coil

- Multiple half-lapped layers of 2 inch wide glass tape were hand applied over the OH coil diameter to form the outer ground wall.

PPL Coil Shop

36


VPI & Electrical Testing of OH Coil
OH coil in VPI mold
During OH VPI
The coil was successfully VPI'd and electrically tested
37

Outer Ground-plane and Pre-load Assembly

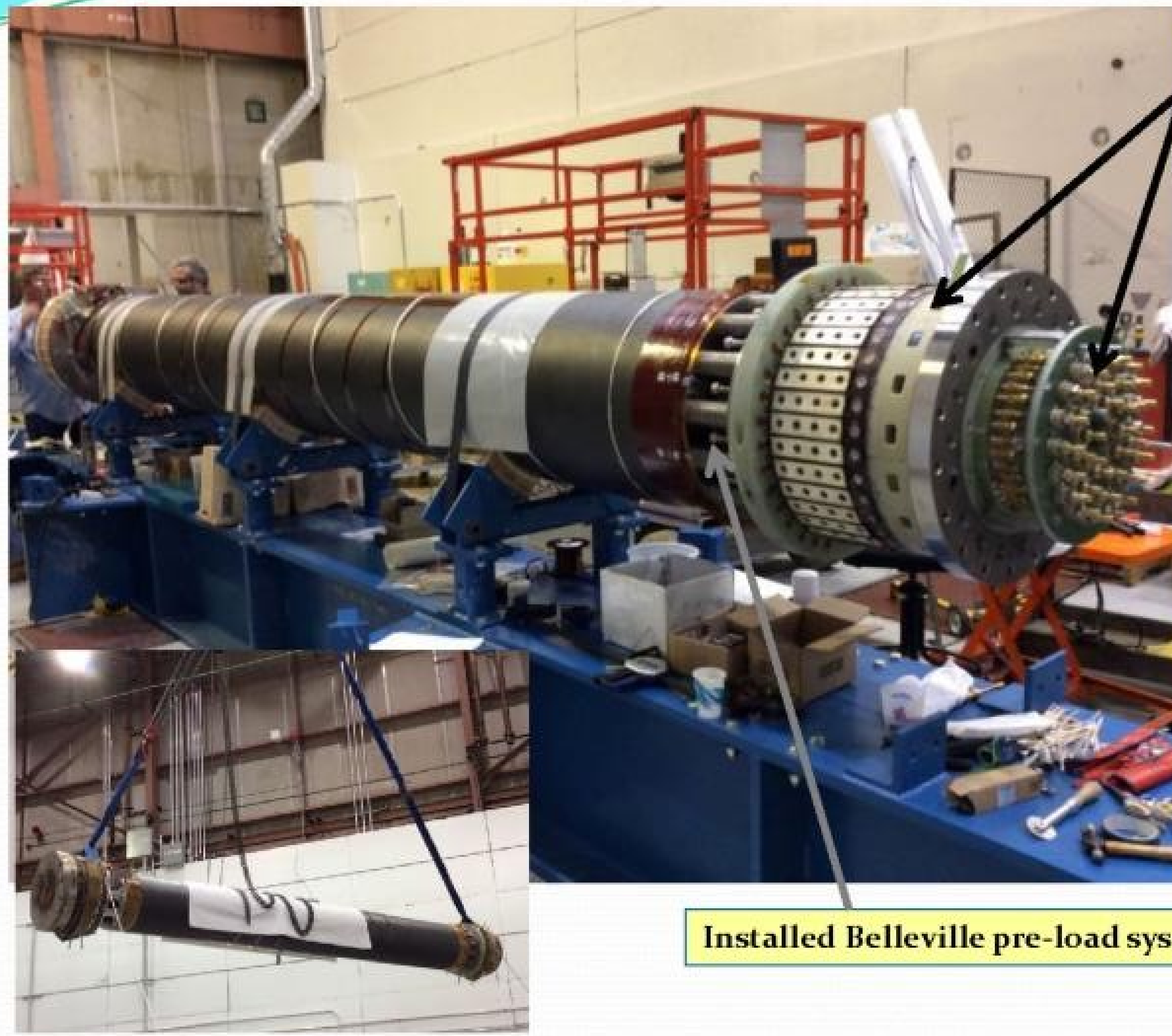
- ***The "Aquapour could not be removed as planned because epoxy had migrated into the "Aquapour" material. Project decision was made to abandon "Aquapour" in place.***
- The outer surface of the OH coil was then painted with a ground-plane coating.
- The Belleville washer pre-load assembly was then installed

Ground-plane outer coating

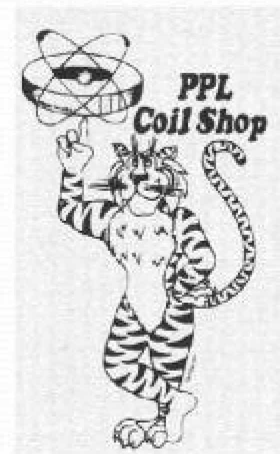
Belleville washer pre-load assembly

38

Center-stack Nearing Completion- NSTX-U



Finalized Inner TF cooling fittings and G-10 torsion crowns



Installed Belleville pre-load system

39

Raised OH/TF Bundle for final assembly details

The OH/TF bundle was raised to the vertical position so that the surface diagnostics and micro-therm thermal blanket could be installed.

OH/TF Bundle weighs approximately 23,000 pounds without PF coils or casing

40

Installing Lower PF1A Coil Assembly

- PF1A had to be lowered over the entire length of the OH/TF bundle prior to the installation of diagnostics

PF1A coil weighs approximately 1800 pounds

41

Installed OH Diagnostics and Thermal Blanket

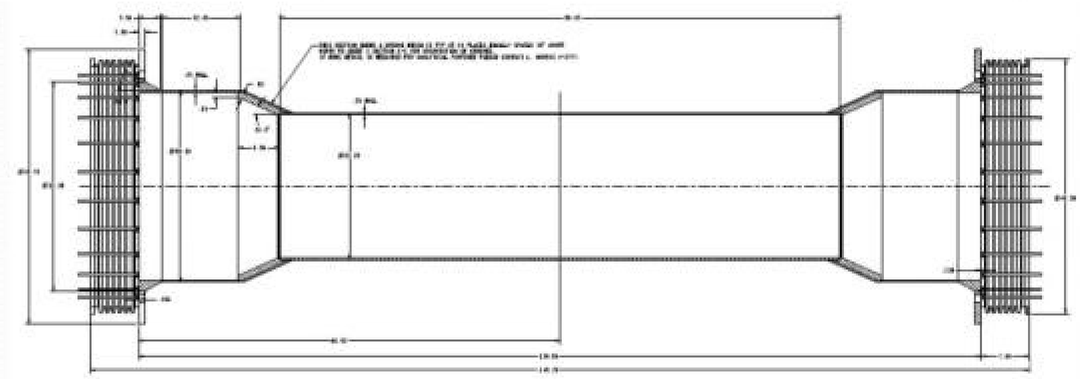
42


Lower OH/TF Assembly & Prepare for Transport
Quality Trademark
PPPL
Coil Shop
43


OH/TF Assembly Ready for Transport to D-Site
44


Transport OH/TF Assembly to D-Site
45

Centerstack Casing



- The Centerstack casing and bellows are fabricated using Inconel 625 and provides the inner vacuum vessel wall for the NSTX vacuum vessel. It also provides the structural support for the plasma facing components and surface diagnostics. Active cooling in the IBD regions has been incorporated in the upgrade.
- The casing was fabricated by Martinez-Turek, Inc. in California

46


Center Stack Casing Fabrication
fabricated by Martinez-Turek, Inc.
47

Tile Installation on Casing

- Carbon tiles and diagnostics were added to the surface of the Centerstack casing by PPPL personnel.

48

Inner Poloidal Field Coils

- **General Description:** Includes three pair of Poloidal Field coils [PF1A, PF1B and PF1C]. These coils were constructed using extruded oxygen-free silver-bearing copper conductor w/cooling hole. Individual turns are insulated with co-wound glass/Kapton insulation applied in multiple half-lapped layers. Multiple half-lapped layers of S2 glass ground-wrap is applied over the finished wound coils. The wound coils were epoxy impregnated using epoxy impregnated using CTD-425 system a 2-part system with Epoxy (EP) and Cyanate Ester (CE) catalyst in Part A and Cyanate Ester (CE) in Part B.
- The Poloidal Field coils were wound directly onto their support structure and VPI'd into the structure.
- The Inner PF coils were fabricated by Everson-Tesla Co.

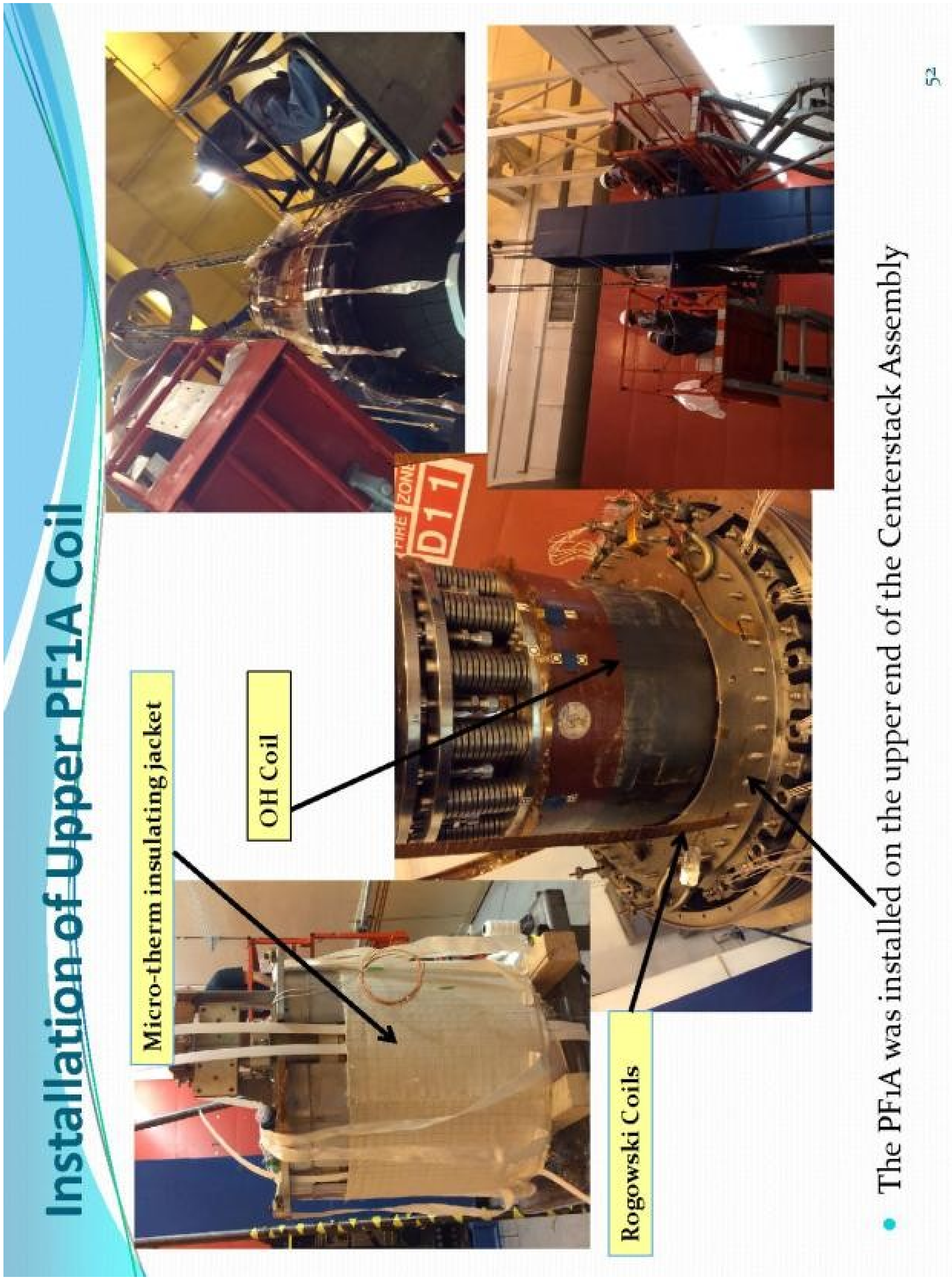
49


Fabrication of Inner Poloidal Field Coils
50

Installation of CS Casing with OH/TF Bundle

- Photos of the Centerstack casing being lowered over the OH/TF bundle

51


Installation of Upper PF1A Coil
Micro-therm insulating jacket
OH Coil
Rogowski Coils
FIRE ZONE
D11
The PF1A was installed on the upper end of the Centerstack Assembly
52

Final Installation of the New Centerstack Assembly

- The Completed Centerstack Assembly was installed into the NSTX vacuum vessel on **October 24, 2014**
- The full Centerstack with rigging weighs less than **30,000 pounds**

53


Final Installation of the New Centerstack Assembly
Installation photos
54

Appendix J

Objective Evidence for KPP's

>50 mA plasma shot

NSTXU Demonstrated Performance Objective Evidence #1

KPP: The major milestone marking the transition from a fabrication project to an operating facility is the first plasma milestone (CD-4). First plasma is defined as an ohmically heated discharge > 50 kA at a toroidal magnetic field of > 1 kG.

Status: Achieved 8/10/2015.

	KPP Goal	Achieved
OH Discharge	>50kA	>100kA
TF Magnetic Field	>1kG	5kg

Supporting objective evidence attached.

Independent Certification

David A. Gates Digitally signed by David A. Gates DN: cn=David A. Gates, o=PPPL, ou=Advanced Projects, email=dgates@pppl.gov, c=US Date: 2015.08.11 14:43:34 -05'00'

David Gates
Head, Advanced Projects-Stellarators

Approval

Ron Strykowsky Digitally signed by Ron Strykowsky DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.11 15:49:58 -04'00'

Ronald Strykowsky
NSTXU Project Manager

Approval:

Stewart Prager Digitally signed by Stewart Prager DN: cn=Stewart Prager, o=Princeton Plasma Physics Laboratory, ou=Director, email=sprager@pppl.gov, c=US Date: 2015.08.11 16:46:49 -04'00'

Stewart Prager
PPPL Director

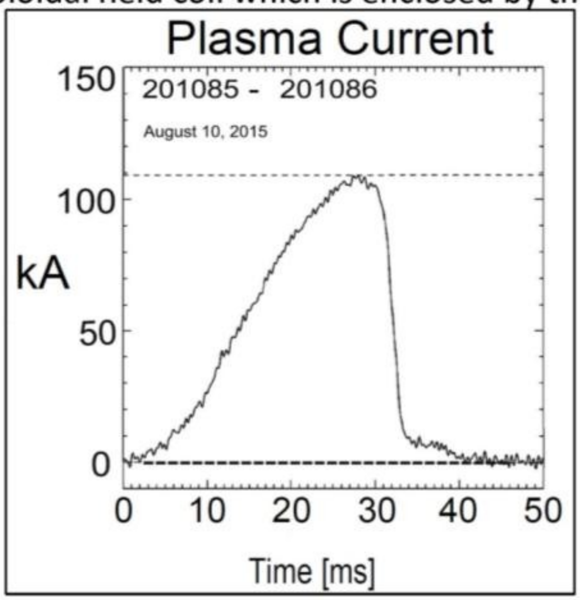
Appendix J

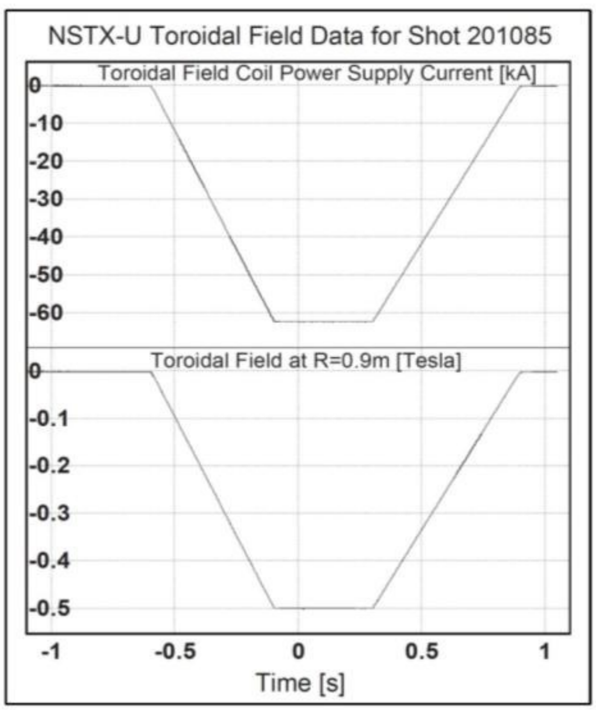
Objective Evidence for KPP's

<u>>50 mA plasma shot (continued)</u>

Plasma current (top) and toroidal field data (bottom) for ~100kA,
B_T = 0.5T plasma in NSTX-U for CD-4 KPP
(note: 0.5T = 5kG).

The NSTX-U plasma current Rogowski loop was calibrated using the PF1C Lower poloidal field coil which is enclosed by the Rogowski.





2

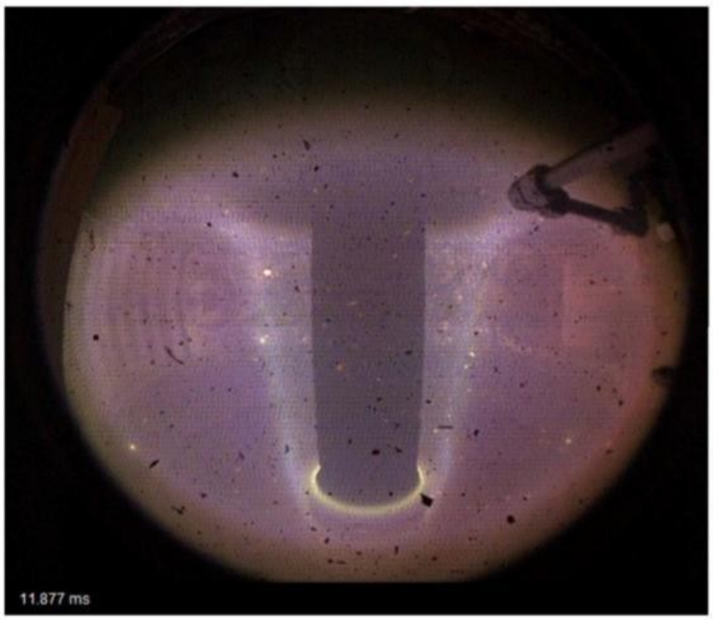
Appendix J

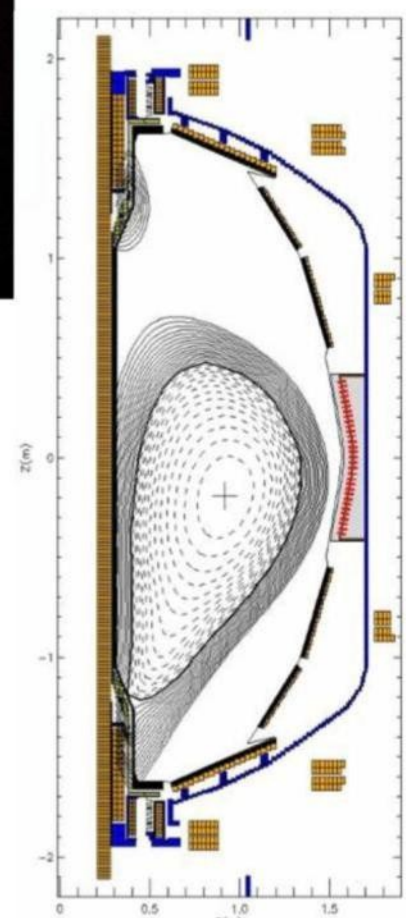
Objective Evidence for KPP's

<u>>50 mA plasma shot (continued)</u>

Camera image (left) and EFIT reconstruction (right) for NSTX-U CD-4 KPP plasma

NSTX-U Shot 201085





Appendix J

Objective Evidence for KPP's

>40 kV Neutral Beam Shot

NSTXU Demonstrated Performance Objective Evidence #2

KPP: The installation of the second neutral beam on NSTX shall be considered complete at the stage where each item below has been demonstrated:

a. Beamline water, vacuum, cryogenics, and feedstock gas services have been attached to the beamline;
b. A Torus Isolation Valve and duct interconnects the NSTX vacuum vessel and the neutral beamline;
c. Local Control Centers have been powered on to monitor power supply status, and;
d. Project will be verified as complete when a 40,000 electron-volt beam has been produced and injected into the armor for .050 seconds.

Status: Achieved 5/11/2015.
Five 45KV @ 12 amps shoots into the armor for >50ms. Attached are PDF's of the armor TC's(pre and post shoots), RSView page showing the status of the beam systems, and the scope traces showing the wave forms.
Supporting objective evidence attached.

Independent Certification

8/6/2015

David Gates
Head, Advanced Projects-Stellarators

Approval Ron Strykowsky

Digitally signed by Ron Strykowsky
DN: cn=Ron Strykowsky, o, ou=PPPL, email=rstrykow@pppl.gov, c=US
Date: 2015.08.06 12:38:15 -04'00'

Ronald Strykowsky
NSTXU Project Manager

Approval:

Stewart Prager

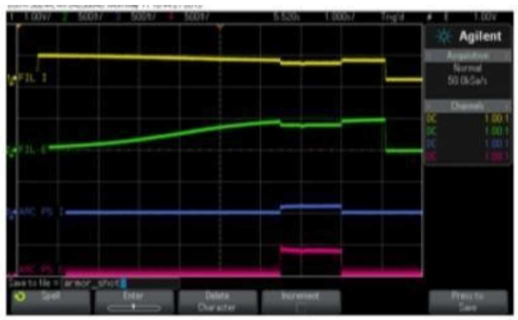
Digitally signed by Stewart Prager
DN: cn=Stewart Prager, o=Princeton Plasma Physics Laboratory, ou=Director, email=sprager@pppl.gov, c=US
Date: 2015.08.06 13:33:09 -04'00'

Stewart Prager
PPPL Director

Appendix J
Objective Evidence for KPP's

>40 kV Neutral Beam Shot (continued)

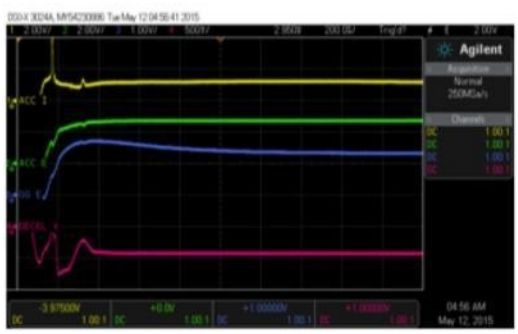
Armor shot



Armor shot probes

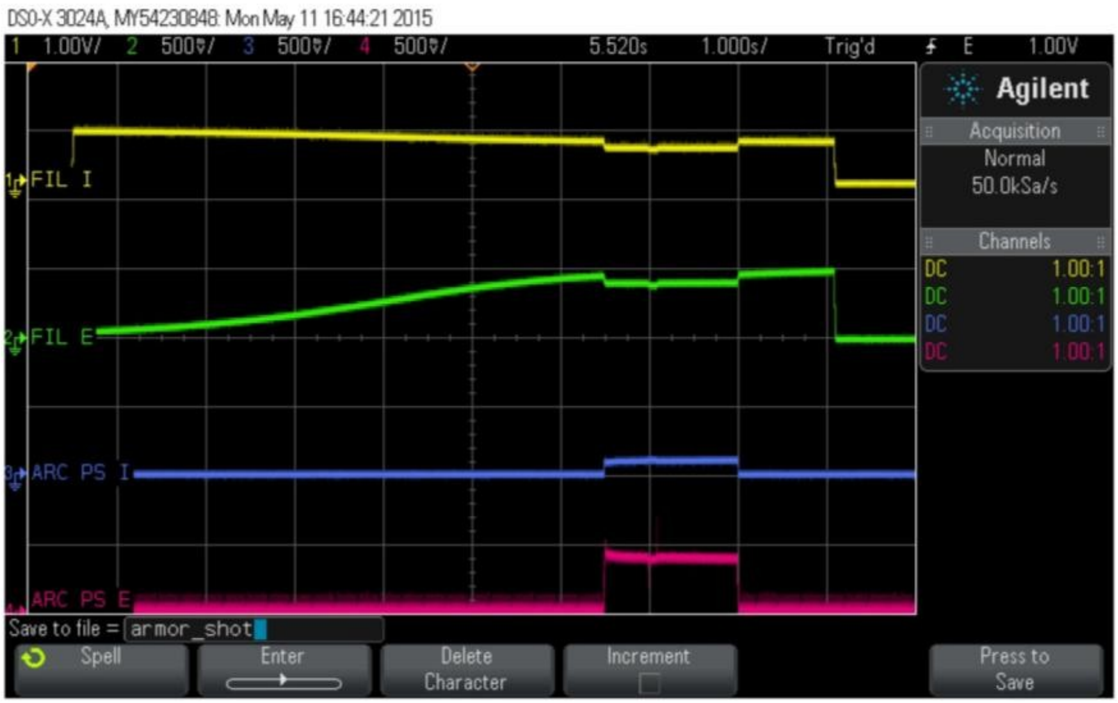
Armor shot

Armor shot fast



Appendix J
Objective Evidence for KPP's

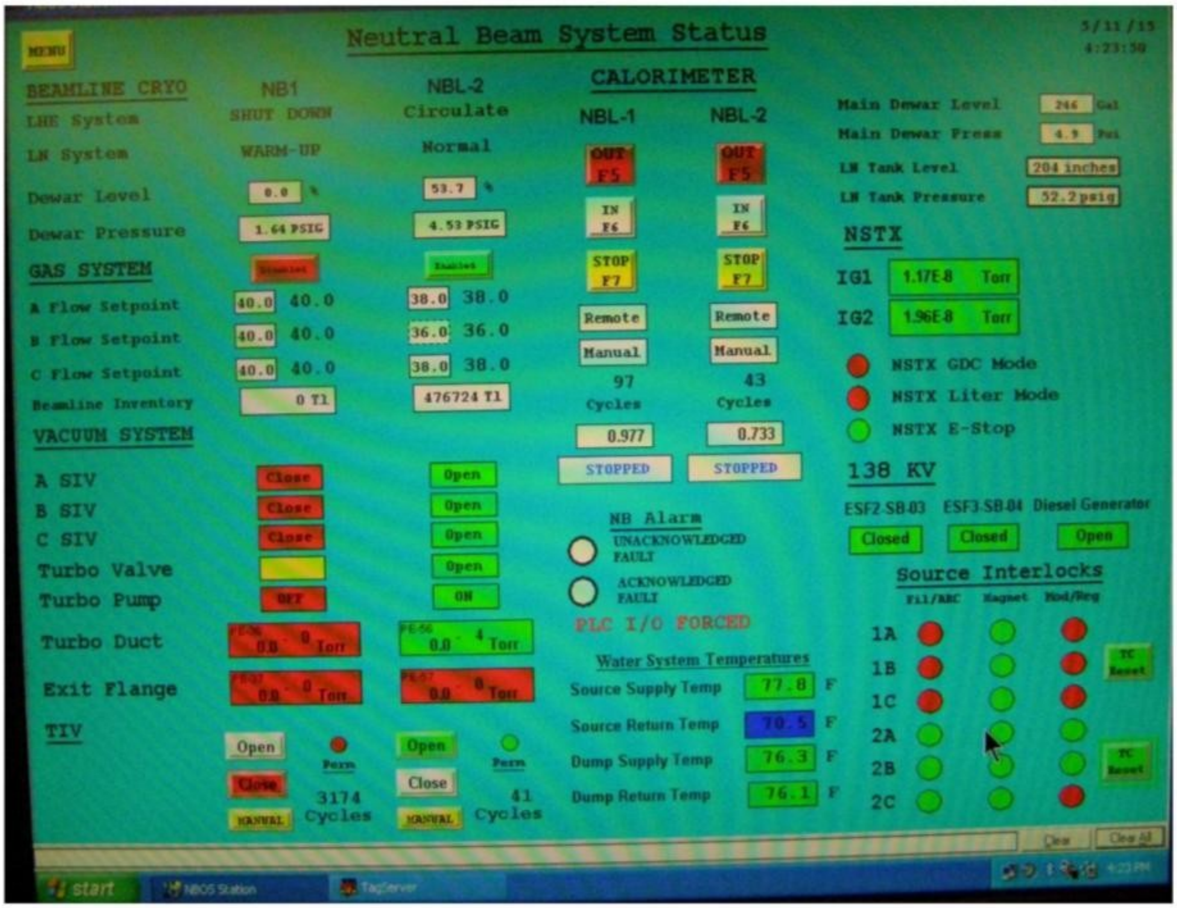
>40 kV Neutral Beam Shot (continued)



Appendix J

Objective Evidence for KPP's

<u>>40 kV Neutral Beam Shot (continued)</u>

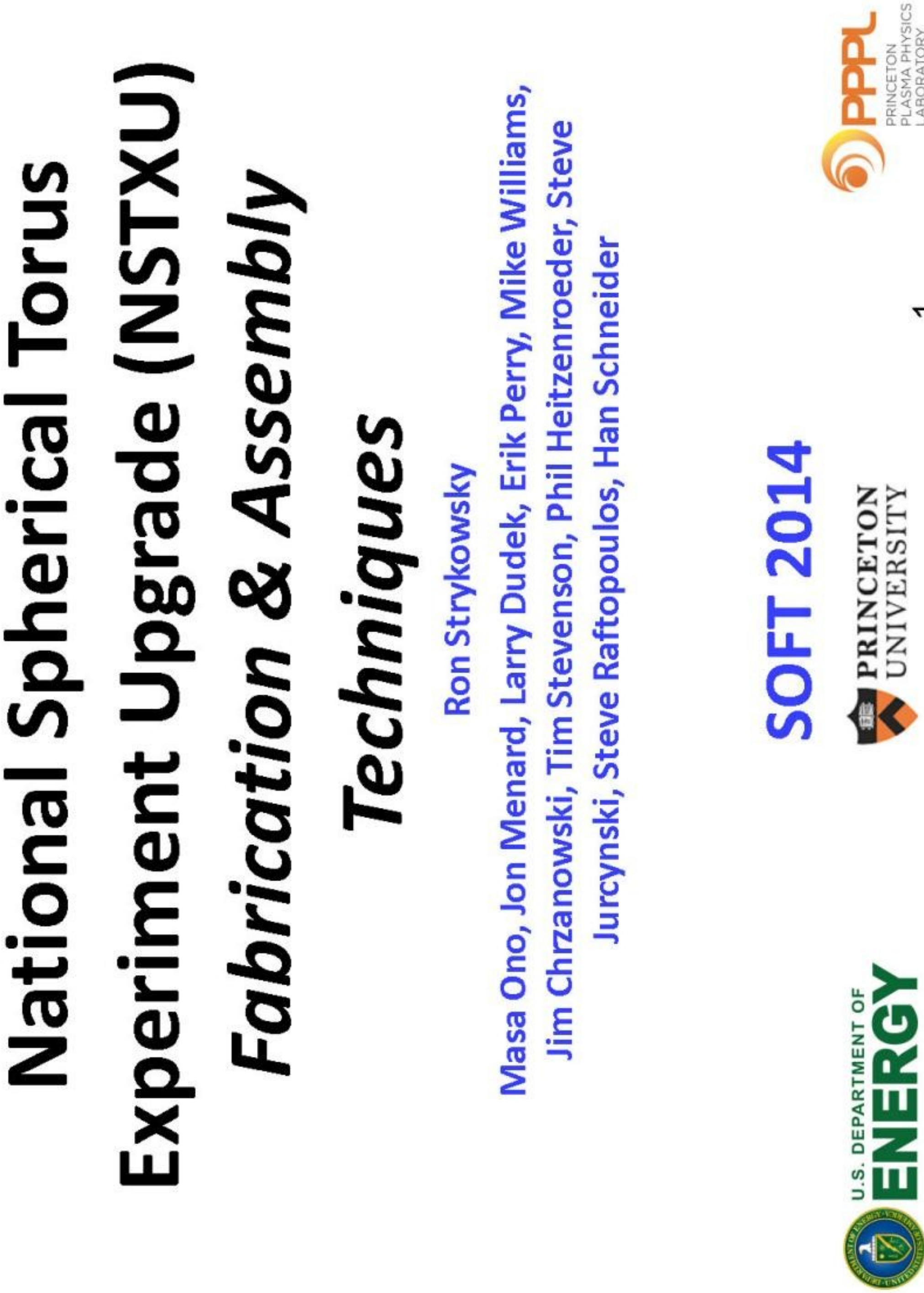


Appendix J
Objective Evidence for KPP's

<u>>40 kV Neutral Beam Shot (continued)</u>

NB ARMOR TC rev 2.vi
C:\Users\grossi\Desktop\NB injection sys Armor TC project\NB ARMOR TC rev 2.vi
Last modified on 5/6/2015 at 2:30 PM
Printed on 5/11/2015 at 4:21 PM

Appendix K
NSTXU Fabrication and Assembly Techniques



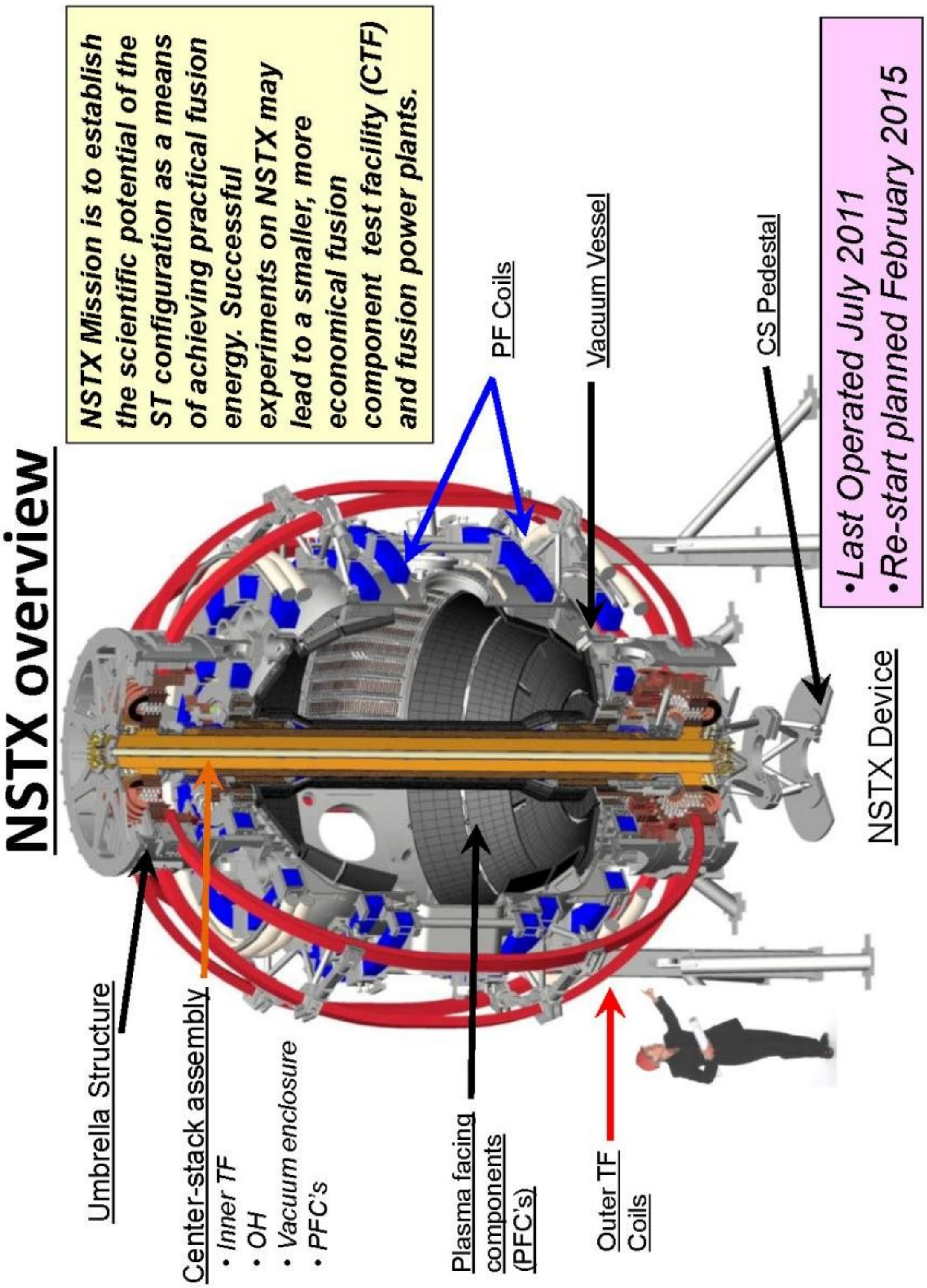
Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

Acknowledgement

- Our thanks to the many PPPL physicists, engineers, designers, technicians, machinists and support staff and subcontractors whose combined expertise and efforts made this upgrade possible.

Appendix K
NSTXU Fabrication and Assembly Techniques (continued)



NSTX Upgrade Project Mission

1) **2 X field and current**
   - Toroidal magnetic field of up to 1 Tesla (presently 0.55 Tesla)
   - Plasma current up to 2 Mega-amp (presently 1 Mega-amp)
   - Increased pulse length from ~ 1 sec to 5.0 sec
2) **2 X neutral beam power & more tangential injection**
   - Install a second neutral beam line
   - Beams tangent to radii 130cm, 120cm and 109.4cm
   - Configure NB1 and NB2 so they can operate together or separately

Centerstack Scope

- **Inner TF bundle** ***(Friction Stir Welding, Cooling tube soldering , & VPI techniques)***
- **New TF Flex strap & lead extensions** ***(Use of Wire EDM and EBW)***
- **New OH coil** ***(Conductor winding over Aquapour)***
- New inner PF coils
- **Enhance outer TF & PF supports** ***(use of mockups)***
- Reinforce umbrella structure
- **Passive plate upgrade** ***(EBW)***
- Power systems changes

Second Neutral Beam Scope

- Disassemble and evaluate an existing TFTR beamline
- Decontaminate and Refurbish for reuse
- Relocate pump duct, racks and numerous diagnostics to make room in the NSTX Test Cell
- **Install new port on vacuum vessel to accommodate NB2** ***(Use of mockups)***
- Move NB2 to the NSTX Test Cell
- Services being re-configured (power, water, cryo and controls)

This upgrade will permit major a expansion of NSTX's scientific mission

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

NSTX-U Fabrication & Assembly Techniques

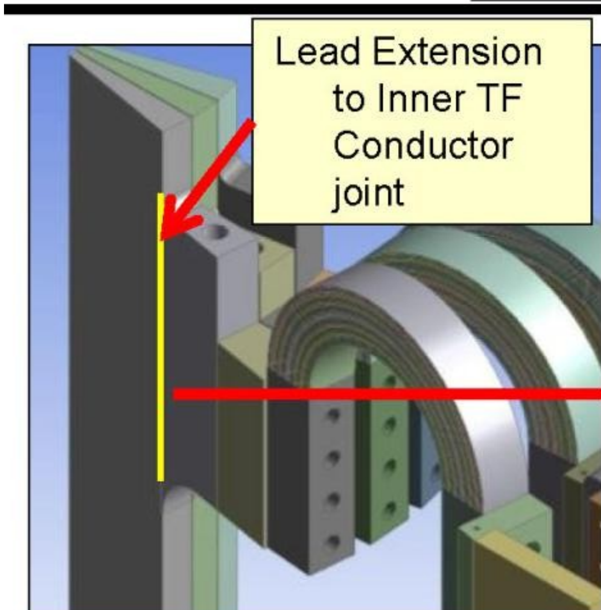
Manufacturing techniques and processes were carefully chosen (or developed):

1. **Friction stir welding of copper** was used to join high strength to high conductivity copper grades in the TF center bundle conductors.
2. A new **non-ionic soldering process** was developed.
3. **Wire Electric Discharge Machining (EDM)** was used in the manufacture of the critical TF High-Current Connector.
4. A carefully planned **Vacuum Pressure Impregnation (VPI)** process with hard metal molds were used to assure the strength and electrical integrity of the center stack.
5. **Cyanate Ester / Epoxy Resin** was chosen because of its maintenance of strength at elevated temperature.
6. **Electron Beam Welding** was used to manufacture the TF Lead Extensions and Passive Plate expansion connectors.
7. A **water-soluble casting material** was used to maintain a thermal expansion gap between the center stack TF and OH winding. Difficulties in its implementation will be discussed.
8. **CAD solid models and mock-ups** assisted in design and assembly planning.

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

1. Friction Stir Welding



What is Friction Stir Welding? [FSW]

- FSW is accomplished at temperatures below melting point of material/ no filler rod/no shielding gas.
- Metal working process using specially shaped rotating pin of hard alloy traversing along joint line.
- Rotation of pin and shoulder plasticize the material, move it across joint boundary and allow to cool and consolidate.
- Eliminates problems such as porosity, solidification cracking and shrinkage.

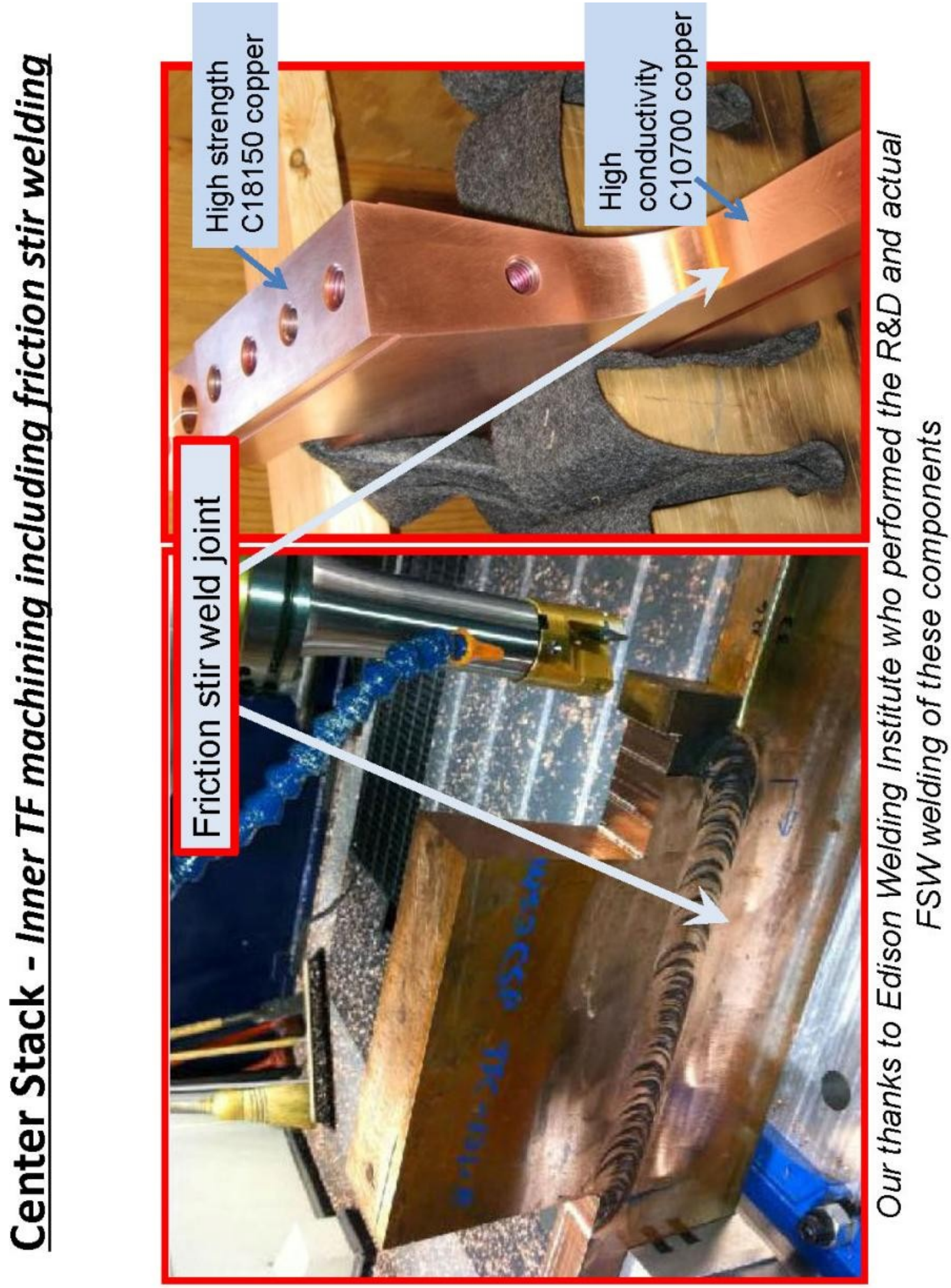
<u>Advantages of FSW</u>:

- **Can join dissimilar metals** (two copper types for NSTX-U: high strength C18150 for joints, high conductivity C10700 for remainder)
- **No heat affected zone; no loss of strength.**
- **Reliable and repeatable process.**

6

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

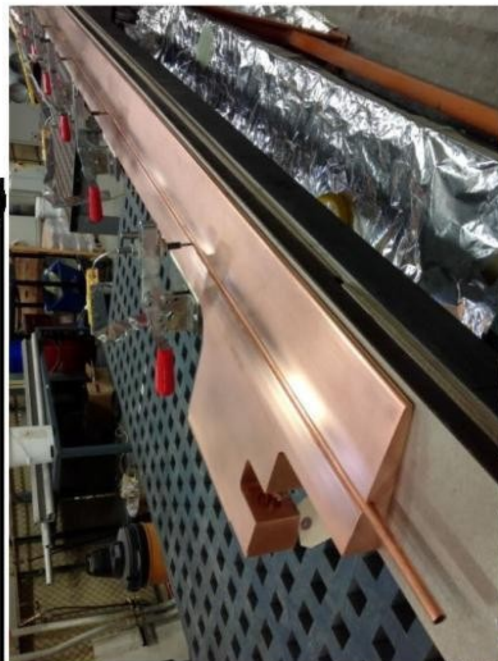


Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

2. TF Cooling tube soldering

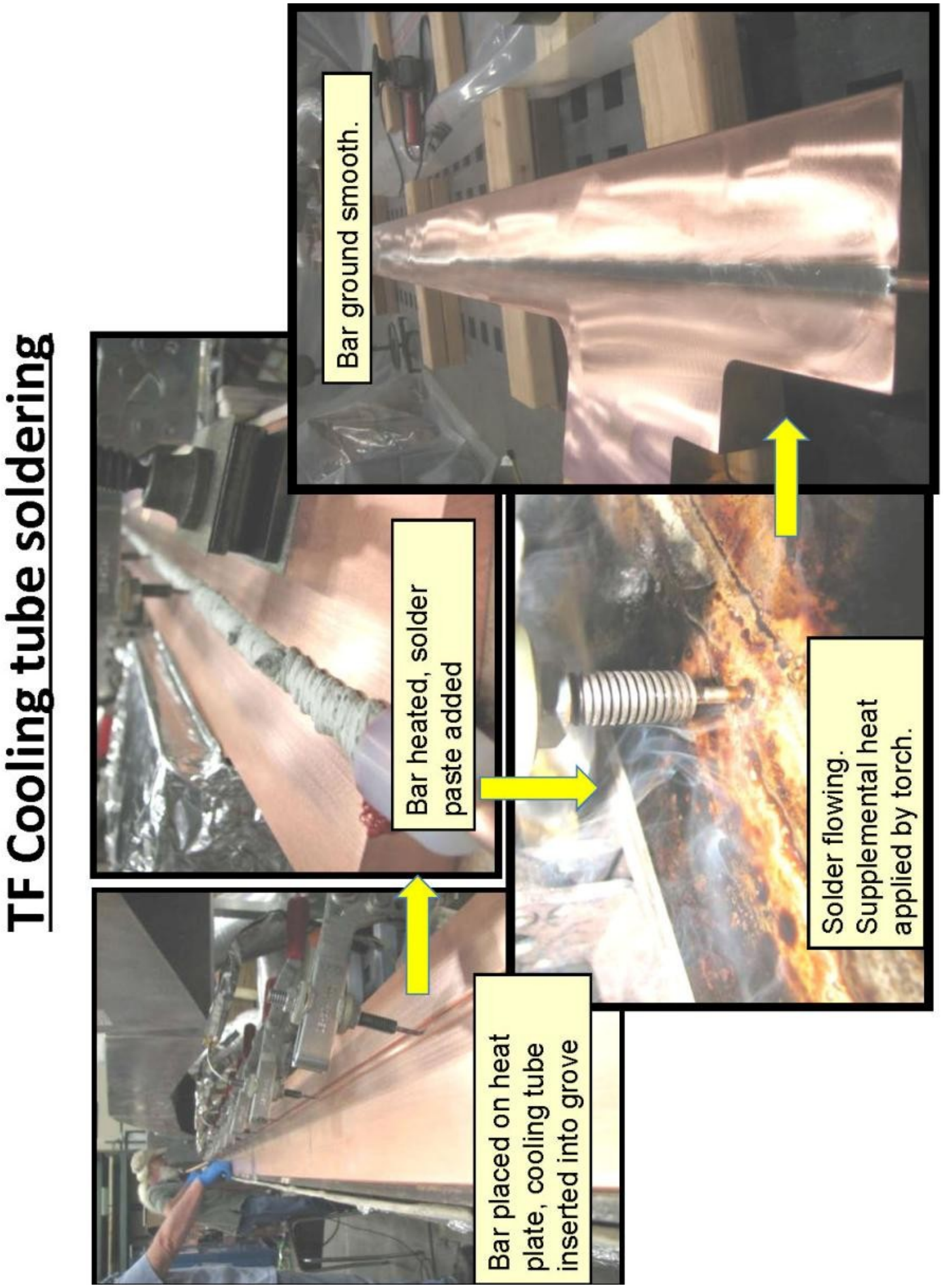
Engineering requirements;
- Use of non ionic flux to eliminate possible carbon tracking between TF conductors.
- Application of uniform heating of solder paste.
- Complete "wetting" of tube to conductor



- **Solder Trials:**
  - Trials have been performed with the assistance of Solder Consultant to verify materials and heating processes
  - Successful heat runs w/actual TF bar
- **Materials:**
  - Solder paste- 96.5 Sn /3.5 Ag w/ GMS based "R" flux [Glyceryl Mono-stearate, Terigitol (a detergent) and Cyclohexlamine Hydro-bromide] *(Thanks to Chemicals & Metals Technology Inc. !)*
- **Heating Method:**
  - Power supply w/heating plate
  - Torch heat to complete process

Appendix K

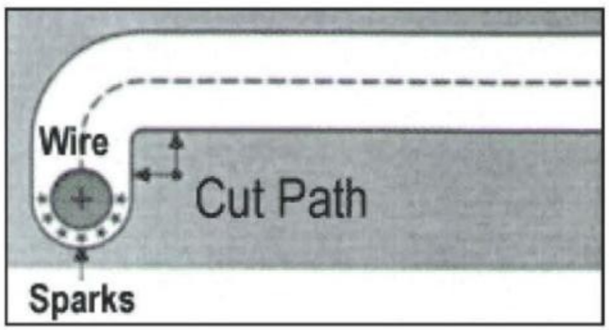
NSTXU Fabrication and Assembly Techniques (continued)

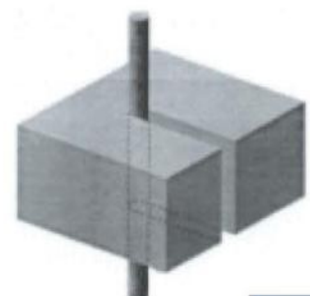


3. Wire EDM – What it is

From Wikipedia, the free encyclopedia

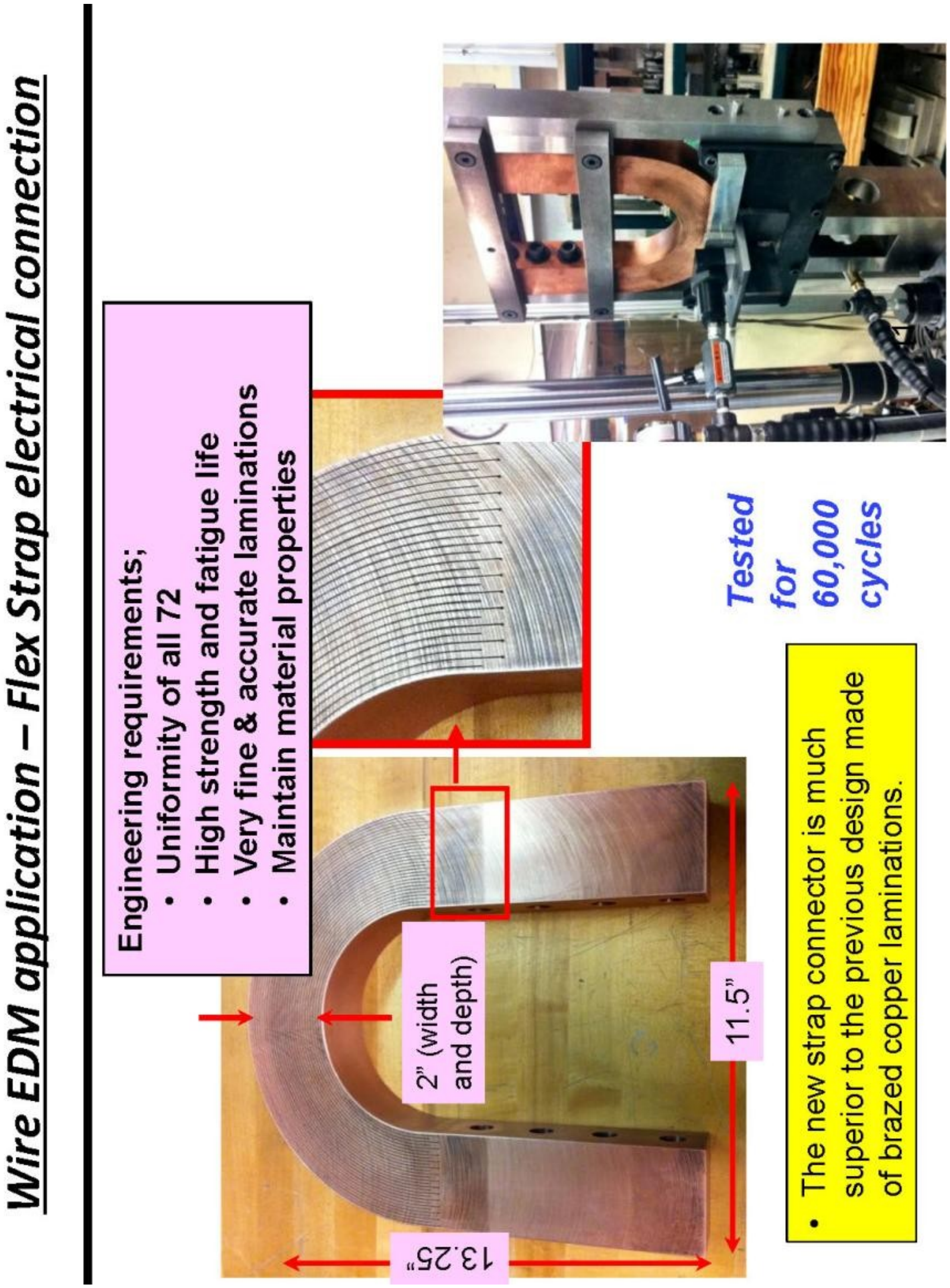
An electrical discharge machine
Electric discharge machining (EDM), sometimes colloquially also referred to as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained using electrical discharges (sparks).[1] Material is removed from the workpiece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the 'tool' or 'electrode', while the other is called the workpiece-electrode, or 'workpiece'.





Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



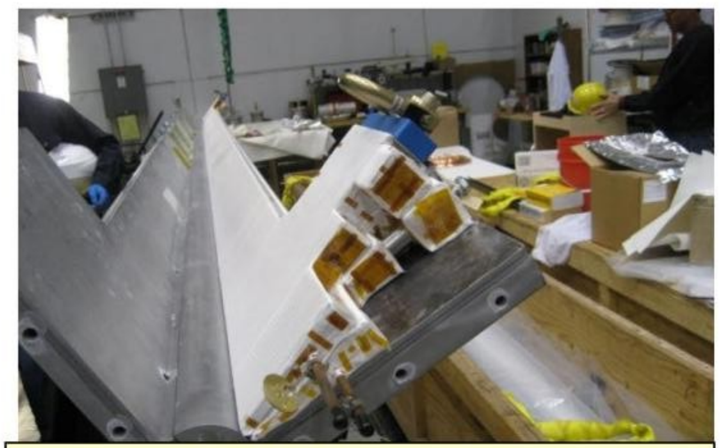
Appendix K

NSTXU Fabrication and Assembly Techniques (continued)

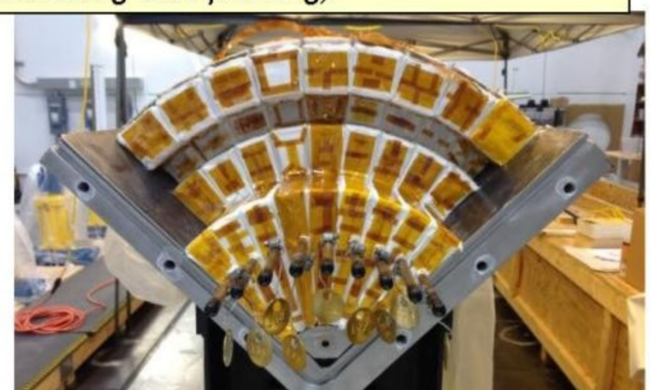
4. Fabrication of Inner TF Bundle – Preparing for VPI

Engineering requirements;
- Complete epoxy wetting of all surfaces (fiberglass, Kapton, conductor) was critical to meet design strength
- Maintenance of strength at 100 C peak coil temperature.
- The required mold ensured uniform final dimensions

Apply turn insulation (dry) by hand *(after gritblasting and priming)*



Assemble individual conductors into Quadrant mold



Assemble 9 conductor (1 of 4 quadrants)

Appendix K

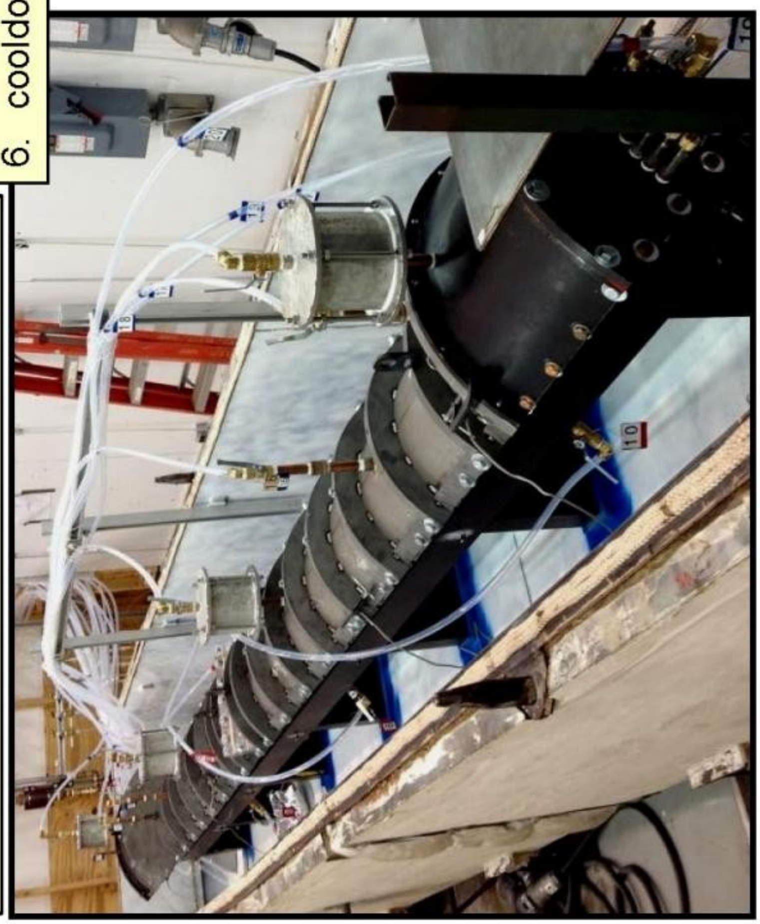
NSTXU Fabrication and Assembly Techniques (continued)

5. Epoxy VPI of Inner TF Bundle

Risk:
- Exothermic reaction of resin- (CTD-425) *(special cyanate –ester / epoxy blend)*
- Dry areas

Benefit:
- Shear and bond strength

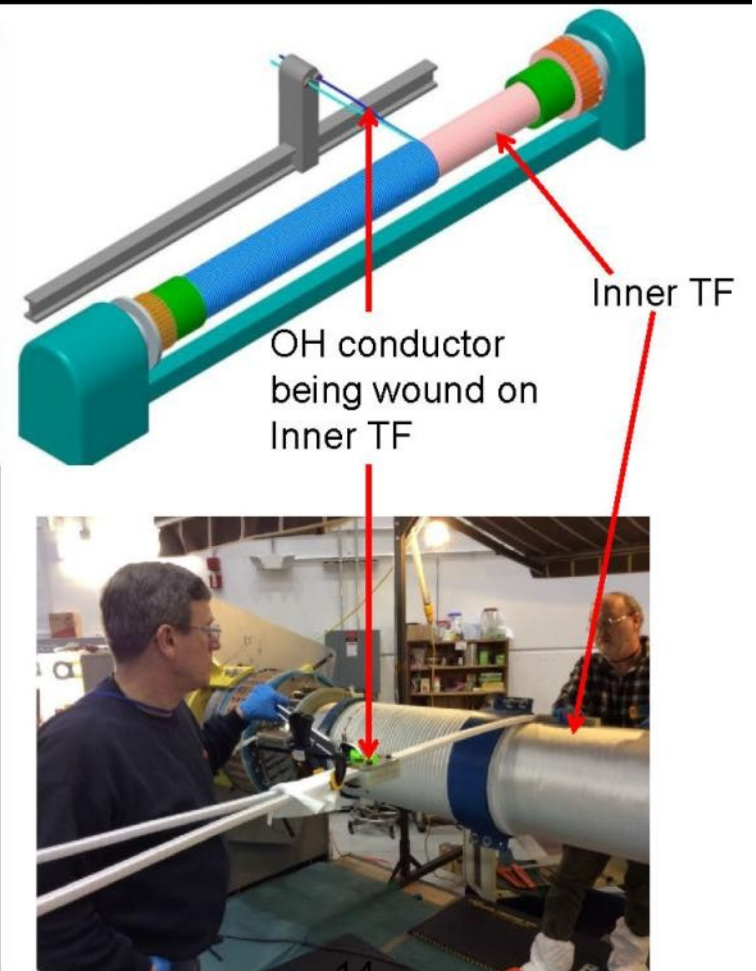
Sequence:
1. Pull vacuum
2. Heat
3. Inject epoxy
4. ramp up temp slowly to 100C and hold
5. Slowly ramp up to 170c cure temp
6. cooldown



6. Conductor Winding – *the plan*

Engineering requirements;

- Since the OH conductor will be wound around the TF coil and to maintain a 0.1" gap between the inner TF and OH coil. Advanced Ceramic Manufacturing's Aquapour™ water-soluble casting material will be used as a temporary winding mandrel.
- Required to allow differential lateral movement between the OH and TF conductor and radial expansion space for a powered "hot" TF coil and cool OH coil.
- The radial expansion of a hot TF coil will frictionally engage the OH winding; the axial thermal expansion of the TF coil results in tensile stresses between the OH turns which, if not controlled, could degrade the electrical properties of the insulation.



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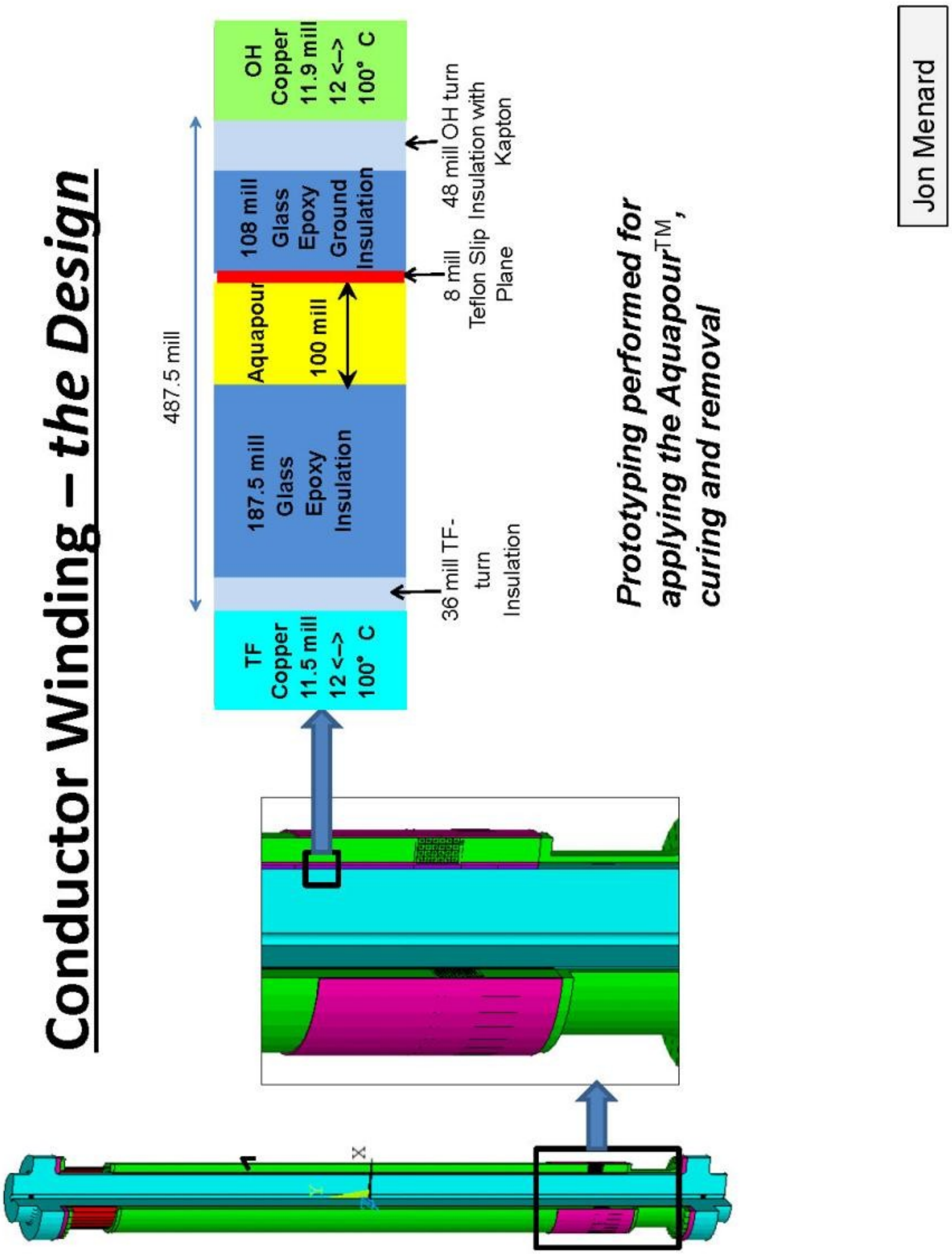
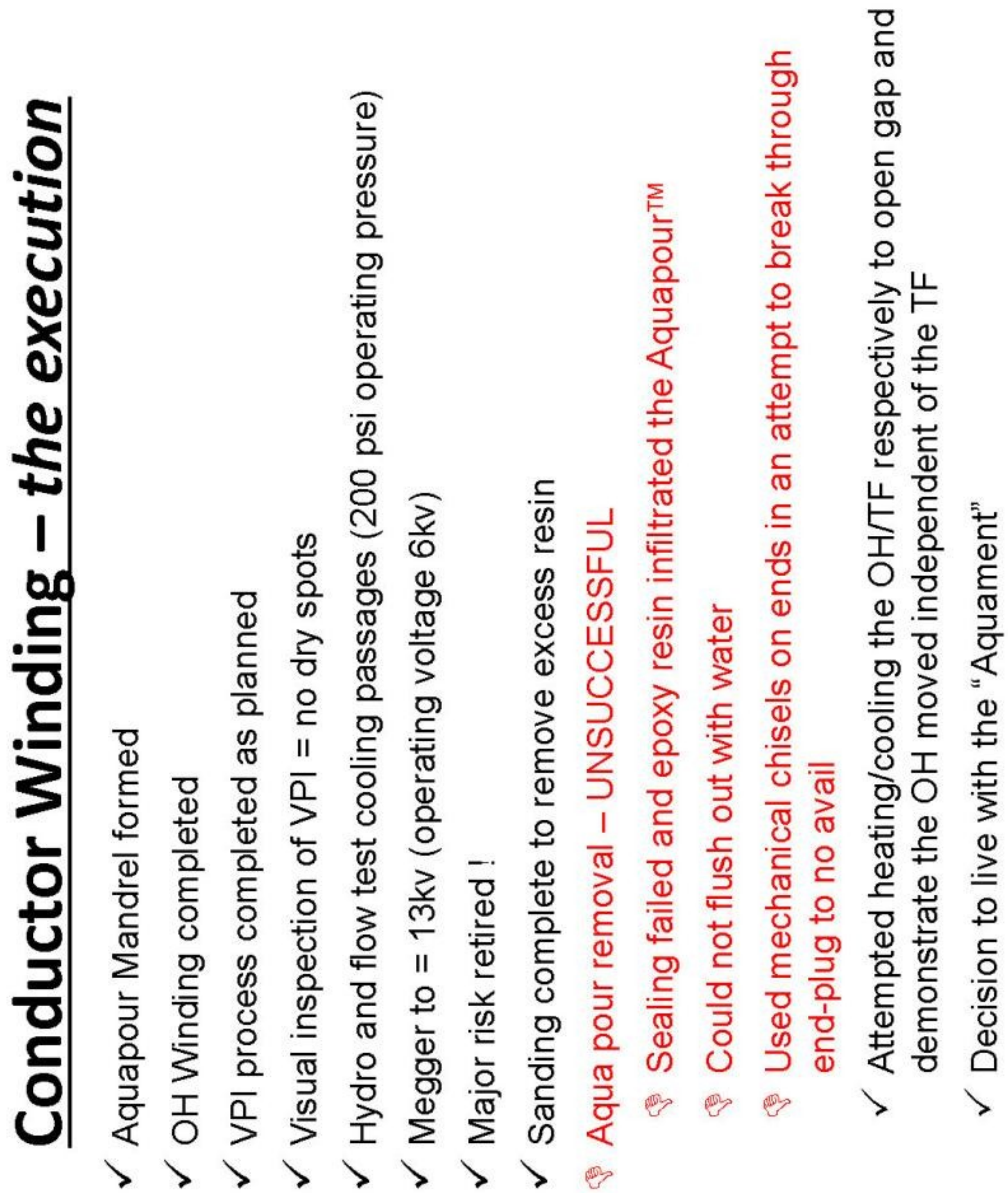
Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Conductor Winding – *epilog*

1. Anticipated thermal radial expansion must now be accommodated by employing engineering and administrative controls during operations.
2. Performance parameters can still be met.
3. Lessons learned! The VPI process is very, very effective. Next time:
   - If possible re-think the design solution (i.e., Teflon spacers, etc.)
   - When the Aquapour solution is best, take extreme care in designing the seals between the Aquapour™ and resin.

7. E-Beam Welding

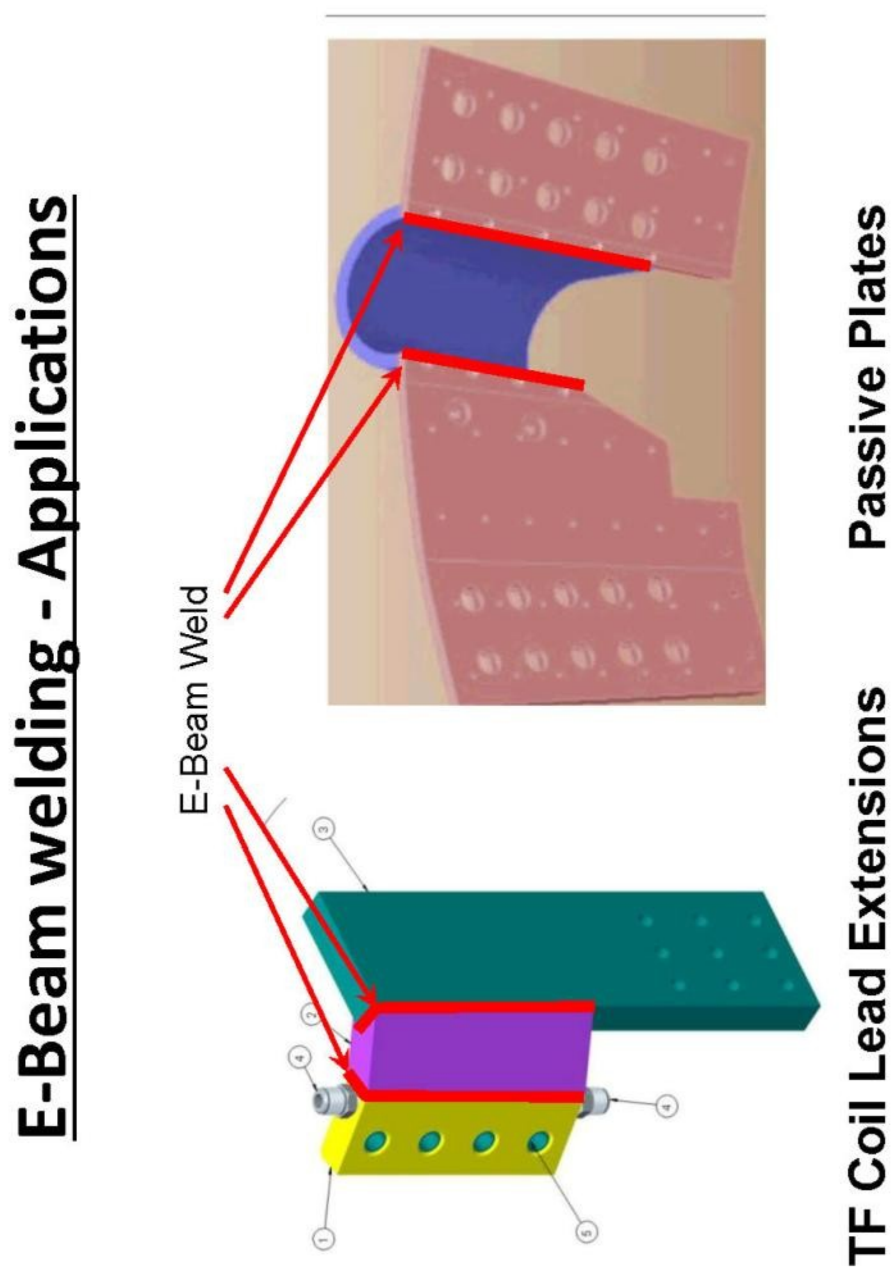
From Wikipedia, the free encyclopedia

Electron beam welding (EBW) is a fusion welding process in which a beam of high-velocity electrons is applied to two materials to be joined. The work pieces melt and flow together as the kinetic energy of the electrons is transformed into heat upon impact. EBW is often performed under vacuum conditions to prevent dissipation of the electron beam. It was developed by the German physicist Karl-Heinz Steigerwald, who was at the time working on various electron beam applications. Steigerwald conceived and developed the first practical electron beam welding machine, which began operation in 1958.[1] American inventor James T. Russell has also been credited with designing and building the first electron-beam welder.[2][3][4]

Engineering requirements;
- Deep penetration of weld
- Low weld distortion
- Narrow application of heat thus the hardness of joined pieces not adversely effected by heat

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



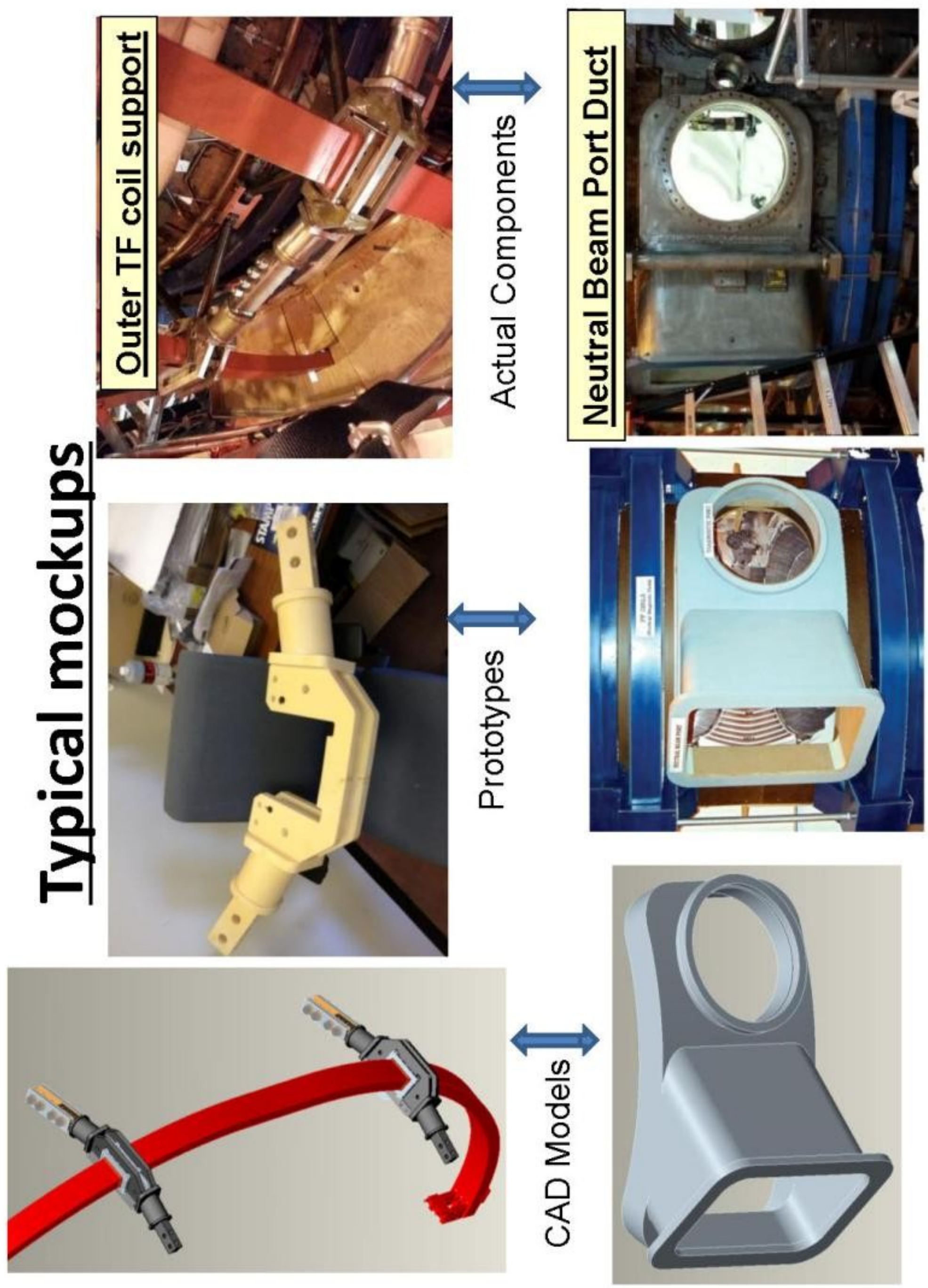
8. Use of CAD Solid Models & Mockup Prototypes

Engineering considerations

- CAD solid models are extremely helpful in developing designs and planning assembly, but mock-up prototypes provide an even higher level of realism for critical engineering details.

Appendix K

NSTXU Fabrication and Assembly Techniques (continued)



Summary

Turning an complex and difficult engineering vision (design) into reality required;

- An understanding of available industry manufacturing processes and techniques
- Value engineering - collaborative peer reviews and dialogue to benefit from the experiences from others
- Clever and pragmatic applications of those techniques and processes into a design that is constructible
- Talented physicists, engineers, designers, and technicians working together as a team

Appendix L

Aquapour Independent Peer Review Findings

Princeton Plasma Physics Laboratory

To: Distribution
From: P. Heitzenroeder
Date: October 14, 2014
Subject: Peer Review of September 8, 2014: Impact of CTD 425 Resin-Contaminated Aquapour on NSTX-U Operations
Reviewers: T. Todd, I. Katradomos (MAST); A. Kellman (GA); J. Irby, W. Beck, D. Terry, J. Minervini, R. Viera, E. Marmar, W. Burke (MIT-PSFC); B. Nelson (ORNL)
Attendees & Participants: J. Makiel, T. Indelicato, B. Sullivan (DOE); M. Williams, M. Ono, J. Menard, S. Gerhardt, R. Strykowsky, P. Titus, H. Zhang, S. Smith, S. Raftopoulos (PPPL).

The motivation for this peer review was described in the Introduction (Ref. 1). To summarize: A plaster-like compound called Aquapour was used to form what was to be a temporary surface 0.100" above the TF center stack surface on which to wind the OH coil. Aquapour is normally easily dissolved by water, and the intent was to remove it after the OH winding was completed to create a thermal expansion gap between the OH and TF windings so that the mechanical and thermal behavior of the two windings would be decoupled. Unfortunately the Aquapour became contaminated with the CTD 425 resin during the vacuum pressure impregnation (VPI) process. The resin-contaminated Aquapour is impervious to water, and is moderately hard. Attempts to remove it with picks, a variety of saws, and pressurized water were unsuccessful. After detailed discussions, the project decided that, rather than risk damage to the TF and OH coils, which were very good electrically, a mitigation strategy based on assuring that the OH coil is always hotter than the TF coil (and thus expanded away from it, permitting the two coils to expand and contract independently) seemed feasible and could be developed. The mitigation strategy was presented in the following two presentations (ref. 3 and 4).

It is worth noting that this risk was evaluated and listed in the risk registry around the time of the preliminary design review in June, 2010. Risk: "unable to completely remove temporary space material between OH and TF." Mitigation Plan: "Administrative controls during operation requiring OH and TF to be powered together."

The mitigation plan that PPPL proposes is outlined below. (The alternative option discussed during the review, which is to build mockups of the OH coil and perform testing to qualify the coil for the expected strain rates, can be revisited in the future.)

- Preheat the OH to create a gap between the TF and OH so that each can thermally expand independently. The gap required is ~0.012". There are two options for maintaining $T_{TF}<T_{OH:}$
  1. ***Pre-heat the OH coil*** using currents before the TF turns on.
  2. Control the shape of the OH S-curve by ***adjusting the amount of pre-charge***.

- **Year 1 and 2 physics program can proceed basically unaffected** since the OH and TF coils are only needed to operate at ~70-80% full operating parameters, even allowing for the proposed OH coil pre-heating. This provides "room" for the temperature rise due to preheating or recharging of the coil.

- Year 3+ requires 2 MA, 1T, 5s operation. To make room for the OH preheating while still permitting the full thermal excursion required, we propose extending the maximum OH operating temperature from 100 ^{0}C to 110-120 ^{0}C after tests to verify this change.

Depending on the maximum temperature, there may be a small (0.2-0.3 s) loss of pulse duration. Operation at τdischarge>3τ_{CR} (plasma current redistribution time constant) will not be affected. **With these changes in operation, the full NSTX-U Physics Program can still be achieved.**

<u>Increasing the maximum OH operating temperature:</u>

- The resin used to Vacuum Pressure Impregnate (VPI) the TF and OH coils is CTD-425, which is a cyanate ester / epoxy blend.
- The primary reason this resin was chosen was to assure maintenance of adequate strength properties at the projected 100 ^{0}C maximum operating temperature.
- DMA test data shows that this resin has a virtually flat storage modulus up to ~120C. The storage modulus behavior indicates that there will be minimal loss of the elastic modulus up to that temperature. *Consequently, we believe that it will be possible to safely extend the maximum operating temperature from 100 ^{0}C to 110-120 ^{0}C.*
  - We plan to verify creep properties. Creep (permanent deformation), can occur when a material is stressed for prolonged periods of time at elevated temperature.
    - Tests are planned to measure the creep behavior of a CTD-425 VPI impregnated mockup of a coil section, but this is not expected to be an issue.
    - The time that the coil will be at temperatures >100 ^{0}C will be limited - allowing for cool-down, it is in the range of 12 minutes per pulse.
    - It will only be a maximum of 10-20 ^{0}C above the design basis 100 ^{0}C.
    - If creep does occur, the preload mechanism (compressed Belleville spring washers) can absorb a modest amount. If more must be accommodated, the mechanism can be re-adjusted or, in the extreme, shims could be added.
    - The preload mechanism contains two sensors to measure solenoid thermal growth or, if creep occurs, decrease in height.

<u>Reviewer Inputs:</u>

Below are answers to the Charge questions and comments from the MIT reviewers and the responses from the Project:

<u>Charge questions:</u>

A. Does our approach with temperature controls appropriately control risk?

You are not making direct measurements of temperature or strain. The I^2t measurements must be good enough and the thermal coefficients known well enough to ensure you know the temperatures are within safe limits, with appropriate margin. Good measurements of inlet and outlet water temperatures and flow rates should be used to add confidence to the measurements. Assuming adequate testing of your new Digital Coil Protection System ensures you can maintain the entire OH coil at least 10 ^{0}C above the TF everywhere, your plans for 2015 and 2016 operation could be carried out with acceptable levels of risk. You should continue to refine your measurement and control capability, your analysis results, and your testing program over the next few months. These issues should be discussed before the readiness review in December.

Answer: RTDs measure the inlet and outlet temperatures for all 4 layers of the OH coil and all turns of the TF coils. RTDs are type A PT100 with accuracy of 0.1C. RTD temperature measurements will be used to periodically calibrate the accuracy of the algorithms used in the DCPS. These sensors will also be used to provide the permissive for the next shot.

10^0C is not proposed as the temperature difference between the OH and TF; rather we propose to keep the TF always colder than the OH, or at worst have their temperatures match. In the future we may assess scenarios with the TF slightly warmer than the OH. See S. Gerhardt's presentation for details of the OH preheat or precharge temperatures proposed.

B. Is the need for qualification tests urgent or can they wait for operating experience and/or physics need?

The characterization of Aquament mechanical properties should be completed before you begin operation. Creep tests on an OH mockup should be part of an ongoing program to prepare for full parameter operation in 2017.

Answer: By ensuring that the OH temperature is above or equal to the TF temperature there will be no mechanical interaction between the two systems. We do plan to cut samples from a VPI'd sample of Aquapour to measure its compressive and tensile strength and modulus. However, since our plan going forward does not require this data, it is just for information for possible future use. Based on the effectiveness of the VPI process and our suspicion that thermal expansion of the OH coil preceded thermal expansion of the TF coil which was interior to it and "insulated" by a layer of Aquapour, it is likely that resin flowed down the entire length of the Aquapour and impregnated the entire cylinder of Aquapour. The VPI'd Aquapour was found to be very tough (though not as tough as the resin) and hard to break up; we feel that it will not break up into pieces small enough to fall into the thermal expansion gap (~0.012") . Regardless, we will periodically monitor the bottom of the solenoid for any evidence of particles falling out.

C. Is the present and future work that is planned comprehensive enough to support our research goals?

If you continue to refine your models and do tests consistent with those mentioned in Pete's presentation, you will be able to make very good progress on your research goals. We still have questions and comments you should consider as you plan the engineering work ahead:

1. We strongly recommend tests to evaluate the Aquapour properties, including mechanical and thermal. This test should also measure the rate of penetration of the resin as a function of time during the VPI process.

   Answer: We do plan to evaluate the mechanical properties of Aquacement (see B above). The thermal conductivity, although not measured, was observed to be low during heating of the assembly during the relative motion tests (below). It will not have any appreciable effect on the dT between the two coils or cool-down during operation.

2. How was the relative movement of the OH relative to the TF core measured? Was it symmetrical top/bottom or with one end of the OH coil fixed? Symmetrical growth top and bottom does not ensure that the OH is free to move relative to the TF.

   Answer: Normally the OH coil is fixed on the bottom and expands towards the top. It was measured by dial indicators. For this test, the bottom support was removed and the coil expanded both ways (not quite symmetric, ~0.040" bottom; 0.060" top).

3. OH coil cool-down analysis which includes the Aquacement thermal properties should be performed.

   Answer: The heating time-temperature behavior during the relative motion tests demonstrated that the Aquacement has relatively poor thermal conductivity and will not appreciably affect cool down during operation (See B above). .

4. What is the degree of accuracy of the temperature measurements and is the error within the allowable delta T for safe operation of the coils?

   Answer: Thermal calculations will be done within DCPS. These calculations will be calibrated by the RTD's which measure the water inlet and outlet temperatures. The accuracy of the RTDs is 0.1 degrees; the calculation accuracy and calibration accuracy together will be better than ~1-2% , which is safe for assuring adequate dTs between the coils.

5. What type of electrical testing will be performed on the coil once it is installed in the tokamak, and at what temperatures will the tests be performed?

   Answer: After installation, impulse tests will be repeated at 5 kV and hi-pot tested at 9 kV and compared to the previous measurements. The tests will be performed at room temperature. A subsequent Integrated System Test Procedure (ISTP) will qualify the coil for operation.

6. Cool-down fault analysis should include failure of any or all of the coil cooling systems. Are the implications of such events benign? As one example, if the TF cooling system failed at the end of a high performance pulse, what will happen to the TF and OH temperatures (and gradients) as the coils cool passively through conduction and convection to the rest of the structure?

   Answer: The coils do not require active cooling during a pulse for safe operation. In a passively cooled condition, analyses show that the TF cools faster than the OH due to the TF flags which extend from the coil in the umbrella structures and acting like cooling fins; this is a desirable condition. If the TF cooling water trips or has a flow problem, the programmable logic controller (PLC) can be programmed to stop the flow of the OH cooling water. As a result of this review, we do plan to program the PLC to stop the flow of water to the OH if the TF cooling water trips or has a flow problem.

7. Do the 4 wires (intended to help remove the Aquapour, but now trapped in the coils) pose any electrical or mechanical risks? Issues could include stress concentration and peaking of electric fields. Is there modeling that could/should be done?

Answer: The electrical insulation has large factors of safety (see Att. 3). An ANSYS 2-D electrostatic model indicated no risk electrically since the calculated electric field is 1.8 MV/m compared to a dielectric strength of 30 MV/m for G-10 (which has comparable electrical properties to VPI impregnated fiberglass) and 3 MV/m for air. They pose no mechanical risk.

8. Is the time between pulses using the new cool-down scenario adversely affected?

   Answer: The cool down scenario will not be affected due to Aquacement issues.

9 Slide 31 in Titus's presentation shows one preliminary simulation of post-shot cool-down, but in the case shown it appears the stresses might be as high as 16 MPa, which seems too large (based on slide 4 from the same presentation). Pete says "more analysis required". When will that be complete, and will it be reviewed?

   Answer: Although not related to the Aquacement issue, the cooling wave phenomena was recognized and is being further analyzed. The analyses are expected to be completed in early November, and a Peer Review will be held shortly after that.

10. What about a TF crowbar at end of TF flattop, when OH current is back to 0. Slide 4 from Gerhardt's presentation shows a case where the OH temperature gets very close to the TF (within perhaps 3 degrees C). [a]. Are there simulations of cases like this, with a TF crowbar at the end of flat-top? [b]. During the review it was mentioned that a TF crowbar at full current would cause something like an additional 4 ^{0}C temperature rise. A simulation that shows this for 130 kA TF cases with the TF starting at 100 C should be run. [c]. Slide 20 discusses the DCPS algorithm to be implemented for protection, but without more information, it is not clear if this will prevent access to some of the desired (required) operating space. Also, what is the maximum temperature the TF can take, independent of the OH stress considerations?

    Answers: [a] and [b] The DCPS algorithms factor in the temperature rise due to crowbarring. [c]. It may slightly narrow the operating space at the combined highest fields, currents, and pulse durations. That algorithm is conservative as it limits the projected temperature difference between the OH and TF to less than zero; i.e. this enforces the new requirement that the OH temperature is never lower than the TF.

11. Almost all of the simulations for coil temperatures appear to be 0-D. Are important gradient effects being missed? It appears that all of the planned DCPS algorithms assume single uniform temperatures for each coil (OH and TF). Is that sufficient for protection?

    Answer: The cooling analyses with the F-Cool code were 1-D, and these demonstrate that 0-D is sufficient for protection. The analyses have addressed 3-D thermal gradients in the coils.

12. If Aquapour degrades during operations, what keeps the OH centered on the TF? Slide 22 of Gerhardt presentation implies centering shims will no longer be used since there is no room for them now anyway, because of the Aquapour.

Answer: Shims can easily be added on the top end of the solenoid if we do observe Aquapour debris beneath the machine.

13. How will the DCPS changes be implemented, reviewed and tested? A detailed plan is required. What about software bugs, hardware reliability, redundancy, common mode failures?

    Answer: Out of scope for this review, but will be addressed in Operations Procedure OP-DCPS -779. A Failure Modes and Effects Analysis (FMEA) was performed which includes failure modes. Reliability analysis will be included in the DCPS system description which is currently being written.

14. Extensive failure analysis and testing of interlock and temperature difference control and protection systems are necessary.

    Answer: Agree. This will be addressed in the PTP's (Preoperational Test Procedure) and ISTP (Integrated System Test Procedure).

15. How is the temperature evolution algorithm to be calibrated against outlet water temperature and other measurements, and how often is this calibration to be done?

    Answer: See (4) above. Calibration will be performed at the beginning of the run period, which is typically 12-16 weeks. This data is stored for each shot and used for periodic review.

16. What is the range of OH coil temperatures required during normal and off-normal operation? What effect will this have on OH coil insulation over time? When will engineering tests be done for the mock-up section of OH winding for fatigue testing?

    Answer: It will be in the range of 12 ^{0}C to 110-120 ^{0}C, (to support 5s, 2 MA operation) with the exact upper limit decided after the data for the planned insulation creep tests is examined. These tests will be performed in the next year. For the first year, only 70-80% of the GRD I^2 t is required, (Trise~75 ^{0}C). The creep test is being performed to ensure that the OH insulation will not be adversely affected over time. The temperature increase being proposed is modest and far from the glass transition temperature of 180 ^{0}C and will not cause any aging degradation of the insulation.

17. Will DCPS and interlock systems safely handle test shots with TF only and other required test or calibration pulses? The system should be designed to allow them.

    Answer: "TF only shots" will be led by OH preheats sufficient to provide the required thermal headroom. Should this not be done, the DCPS will issue a Level 1 fault.

18. Pete Titus recommends several tests and qualifications for the two possible solutions he presents in slide 19. Are these to be done and, if so, when? These include:

    a. First solution (slide 19)
        i. Recommends strain controlled tension fatigue tests of insulation systems.

ii. Properties of epoxy impregnated Aquapour should be better characterized.

b. Second solution (slide 19) this is our preferred solution.
   i. Plumbing and new operational controls needed.

Answer: We plan to go forward with the solution which avoids interactions between the OH and TF and with 110 -120 ^{0}C max. temperature operation, as discussed on p. 1. Creep tests at 110-120 ^{0}C will be performed. Only operational controls are needed for the elevated temperature operation.

MAST Group Comments:

M1. Several of us considered that it must be possible to do micro-hardness tests on the chips of removed impregnated Aquapour.
Answer: We do plan to perform tests on VPI'd Aquapour samples (see Charge Question B responses above).

M2. I liked the idea raised by someone else of simply measuring the density of the chips and mocking up to some decent sized samples by deliberate impregnation with CTD-450 to cover a range of densities, to check the mechanical behavior, yield strength, etc.
Ans: See Charge Question B response above.

M3. The hi-pot test was helpful and reassuring in its results, but as I said at the time, the wires will create electric field stress concentrations and could conceivably shorten the insulator life against micro-discharges (miniature break-downs within the insulator, exacerbated by electric field cycling), so worth getting someone to analyze sometime, I think.
Ans.: As stated in (7) above, An ANSYS 2-D electrostatic model indicated no risk electrically since the calculated electric field is 1.8 MV/m compared to a dielectric strength of 30 MV/m for G-10 (which has comparable electrical properties to VPI impregnated fiberglass) and 3 MV/m for air.

M4. Temperature rise profiling and control was extensively covered and seemed perfectly OK to me, but I got the impression there had been less work on the temperature fall after each shot. The adverse effects of the cold wave propagating up the solenoid (so it bites the TF vault if that has not been thoroughly cooled beforehand) seemed to be of some concern, and not just because of the Aquapour issues. Indeed, it was said that the solenoid shrinkage being inhibited by it contacting the TF vault would help to reduce the stresses caused by the solenoid diameter transition.
Answer: You are correct; the adverse effects of the "cooling wave" are issues independent of the Aquapour issue. We are re-visiting previous analyses of the cooling wave.

M5 However I agree that a trivial cure to the TF-OH differential temperature problems during cool-down is simply to delay the active cooling of the solenoid until after the outlet temperature of the TF has shown it to have cooled sufficiently. This will work if, as we were told, the thermal time constant between them is measured in hours rather than minutes, and the physicists don't mind waiting an additional five or ten minutes between high-performance shots.

Answer: In normal operation the TF cools down faster than the OH coil. Simulations show similar cool down wave response with and without Aquapour.

M6. Not closely related to this Aquapour problem, I observed that the machine protection system, as sketched perhaps overly simplistically for this presentation, seemed to have many common-mode failure points that could prevent it from carrying out its function rather too often. This would need detailed exploration by more of us with Machine Protection Working Group experience!

Answer: Indeed, the sketch was simplified to provide an overview of the system and should not be considered as an engineering drawing. A FMEA for the DCPS system was performed and has been successfully reviewed.

M7. Similarly it was said that the machine protection would only trip all power supplies simultaneously, by means of electronic shorting switches to force zero voltage on all bus-bars. Compared to JET and MAST systems, this is oddly limited and somewhat brutal to the supplies, and also (I think it was Jon Menard who noted, near the end of the meeting) stops the control systems from being allowed to initiate a controlled termination e.g. when something important has tripped (e.g. the TF or OH), in order to avoid precipitating a high current major disruption. JET uses a cascade of different trip types as any operational limit (single parameter or combined) is approached, in a sequence like power supply internal current clamp, thyristor trigger blocking to create essentially a bridge voltage going to zero, open mains input breakers, fire brutal crowbar. Before all that, we send an alarm to the plasma control system telling it what is likely to trip, so that it can choose one of about a dozen different soft termination scenarios to minimize the chance of a disruption given the specific power supply loss.

Answer: Prior to year 3 of operation, we will have developed and tested algorithms inside the plasma control system analogous to the DCPS which will anticipate exceeding an OH-TF temperature differential limit and other DCPS faults and initiate a controlled plasma current ramp-down before a DCPS trip is triggered.

M8. There was mention of letting the coils cool down on their natural L/R time, but some slides showed a steep TF current decay all the way to zero, as though the supply has two-quadrant behavior. Maybe it has, when not shorted?

Answer: The standard Transrex power supply section has two-quadrant behavior (current in one direction, but voltage in both). The plots that show the TF ramping down quickly are cases where the supply is controlling the current rapidly back to zero, under digital command and NOT in a fault condition.

M9. It was said that sub-cooling TF might exacerbate creep failure, but I don't understand this since creep phenomena are associated with elevated temperature. If the impact of one coil system upon the other was meant, the detail was not explained.

Answer: Sub-cooling of the TF was mentioned as an alternative way of generating the required dT between the OH and TF. This could potentially avoid having to qualify the OH for operation above 100 ^{0}C. If sub-cooled, the TF water temperature would be reduced to 8 ^{0}C. This would require improving the dehumidification of the test cell. We *expect the creep level to be manageable, as discussed in* *<u>"Increasing the maximum OH operating temperature" on p. 1 of this report;</u>* *this is the more cost effective solution.*

M10. My proper engineering colleagues can comment, but I thought Tresca stress, while recognizing the superposition of shear and compression/tension in a generally appropriate way to represent total stress, did not intrinsically relate this to the loci of allowable shear and tension/compression in a composite material at various temperatures and desired fatigue lives, as Mohr plots do?

Answer: The failure criteria we generally use are described in the slide below. Mohr's Circle analysis is used to determine the shear stress in the plane of the composite.

Failure criteria

I-5.2.1.3 Shear Stress Allowable

The shear-stress allowable, S_S, for an insulating material is most strongly a function of the particular material and processing method chosen, the loading conditions, the temperature, and the radiation exposure level. The shear strength of insulating materials depends strongly on the applied compressive stress. Therefore, the following conditions must be met for either static or fatigue conditions:

$$S_S = [2/3\ \tau_O] + [c_2 \times S_{C(n)}]$$

(Resolved to the Interlaminar Shear Plane)

τ_O = the experimentally determined minimum intrinsic shear strength of the material with no compressive load at the temperature and radiation dose representative of the service condition. The strength will represent the lower of the bond shear strength or the composite interlaminar shear strength. This value is to be the minimum value from a sample lot of at least 6. For the sample lot to be valid, the process is to be developed such that the scatter of values shall not exceed +/- 10% from the mean value.

c_2 = an experimentally determined factor for the proposed insulating material based on combined shear and compression testing at the temperature and radiation dose level representative of the service conditions. The constant represents the slope of the dependence of shear strength on compressive stress.

$S_{C(n)}$ = the applied normal compressive stress.

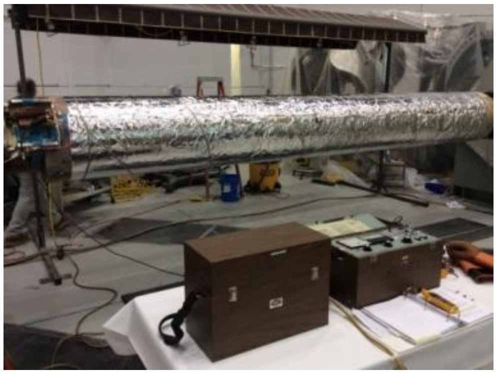
I-5.2.1.2 Tensile Strain Allowable Normal to Plane

In the direction normal to the adhesive bonds between metal and composite, no primary tensile strain is allowed. Secondary strain will be limited to 1/5 of the ultimate tensile strain. In the absence of specific data, the allowable working tensile strain is 0.02% in the insulation adjacent to the bond.

Tsai-Wu has been proposed for Composite materials. It is available in ANSYS but we havn't used it

<u>Electrical Hi Pot Test of OH Coil</u>

Details of the OH coil electrical hi pot test were requested during the review. The photo below shows the center stack during the test. The TF turns were connected together and grounded, the foil over-wrap over the OH coil was grounded, the structure was grounded, and the (4) wires embedded in the Aquapour were grounded. The leakage current from the OH coil to ground was 12μA at 13 kV after 1 min.



References: (posted at ftp://ftp.pppl.gov/pub/Heitz/NSTXU_8SeptPeerRev/).

1. Peer Review Introduction
2. NSTX-U TF-OH Design & Manufacturing
3. Aquapour/CTD-425 Composite Implications for NSTX-U Operations and Research Goals
4. Aquacement problem (Analyses)

Appendix M

Report from NSTX-U Readiness Review Committee

FROM: Arnold Kellman

TO: Mike Williams

SUBJECT: Report from NSTX-U Readiness Review Committee

DATE: 1/20/2015

OVERVIEW OF COMMITTEE ACTIVITY

A Readiness Review Committee met at PPPL December 9 – 11. The purpose of this review was to ensure that the commissioning and subsequent operation of the National Spherical Torus Experiment Upgrade (NSTX-U) could be performed in a safe and environmentally responsible manner. The specific charge questions, prepared by Mike Williams and the NSTX-U staff, are listed below. During the meeting, the committee heard presentations from the PPPL staff, interviewed various PPPL staff members, read procedures, viewed additional documentation, and toured the facility, including the torus hall to address the specific questions in the committee charter. A closeout presentation was made to Stewart Prager, Mike Williams and some of the NSTX-U staff by the committee on Thursday December 11.

CHARGE TO THE COMMITTEE

The following questions were taken from the NSTX-U Readiness to Operate Charter:

1. Do the approved NSTX-U Safety Assessment Document (SAD) and pending Safety Certificate adequately define the safe operating envelope for NSTX-U operations?

2. Are there clearly defined roles, responsibilities and training for NSTX-U operations personnel?

3. Are there clearly defined operating procedures that ensure that NSTX-U is commissioned and operated within the safe operating envelope defined by the NSTX-U Safety Assessment Document (SAD) and Safety Certificate (including off-normal events)?

4. Does the PPPL Activity Certification Committee (ACC) process ensure that configuration changes are adequately reviewed and appropriately documented in the NSTX-U Safety Assessment Document (SAD) and Safety Certificate?

5. Does the PPPL Activity Certification Committee (ACC) process, including approval to proceed by the PPPL ES&H Executive Board Chairperson, ensure that PPPL is indeed ready to begin NSTX-U operations?

6. At the time of project completion, will the NSTX Upgrade Project have delivered the Project Objectives as defined in Section 2.2 of the NSTX-U Project Execution Plan?

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

COMMITTEE MEMBERS

- Arnie Kellman, General Atomics, Chairperson
- Dragoslav Ciric, Culham Centre for Fusion Energy
- Kevin Freudenberg, Oak Ridge National Laboratory
- Tim Scoville, General Atomics
- Jim Irby, MIT Plasma Science and Fusion Center
- Dave Terry, MIT Plasma Science and Fusion Center
- Will Oren, Thomas Jefferson National Accelerator Facility
- Edward Lessard, Brookhaven National Laboratory
- Tom Todd, CCFE (Retired)

GENERAL FINDINGS

- The committee was impressed with the project and the evidence of continued high quality of workmanship and project management.
- The project is ~95% complete with the major production and assembly milestones and the highest risk items completed (CS, DCPS, NB Vessel modification, and NB2 installation) almost complete.
- The recent setback with the Aquapour removal was handled effectively through a combination of internal and external review panels. The expected impact on the physics plan will be minimal.
- Present status gives high confidence in successful completion of project and completion of CD4 in March.
- This committee was not asked to perform a typical Readiness Review. NSTX-U is not ready to resume operations of either the new beamline or plasma operation, as defined by ISTP-001.
    - 20 Project and 28 Operations Engineering Work Packages (EWPs) remain open.
    - 25 chits remain OPEN, 4 are CLOSED but not VERIFIED
    - Some official signed off drawings remain to be updated to "as-built" conditions.
    - PTPs are not yet updated
    - Personnel are not trained in new PTPs or new hardware, software, user interfaces
- The committee was asked to evaluate the SAD, whether the processes, procedures, and training protocols were in place to allow an assessment of readiness to be made by an internal review panel through the ACC process.
- Main conclusions include:
    - Additional work is needed on SAD and definition of Safety envelope.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

- An extensive set of procedures exists to track completion of project, appropriately test all project upgrade elements and existing operational subsystems, and safely operate the device. However, test procedures are not yet updated and would benefit from improvements in quality and uniformity, e.g. allowable ranges in measurements should be included in PTPs, missing signatures, incomplete feedback. An improved focus of the QC/QA group on preparation and completion of procedures is recommended.
- Personnel clearly understand their roles (in some cases multiple) and responsibilities and training is excellent.
- The ACC process is well developed and manned by highly experienced staff members with a broad range of skills. High confidence exists that this process will properly assess Readiness to Operate, similar to what it has done in the past. However, procedural changes to ACC could further improve this well-established process.
- A great depth of institutional and detailed system knowledge exists in present staff. This contributes greatly to thoroughness of reviews and proper functioning and oversight of systems during operations and on-going system modifications and upgrades.
- No commissioning sequence up to full design parameters was presented. The committee recommends that a full commissioning plan be developed including verification of critical stress calculations.
- A potential problem is that since some of the very experienced staff hold more than one key role in the safety and operational management of the facility, there is a tendency to obviate the need for procedures and document trails regarding communication of emerging issues, plant status etc. between these roles.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

ANSWERS TO CHARGE 1

Charge 1: Do the approved NSTX-U SAD and pending Safety Certificate adequately define the safe operating envelope for operations?

- Conditional yes, subject to Items Requiring Resolution

Committee members for Charge 1

- Will Oren (TJNAF), Edward Lessard (BNL)

Method of review:

- Document review, interviews, observations, presentations

Findings

- SAD still in draft
- SAD does not cover entire system's hazards (e.g., ODH in all relevant enclosures)
- Safety basis for the limits in the safety envelope were not described in SAD, but it is tied to the design parameters
- Pressurized water/stress issues in CS are not addressed in SAD/FMEA
- Software QA not addressed in QA section of SAD
- Operating organization structure and authorizations not addressed in SAD
- Linked references or appendices on N2, He and SF6 ODH calculations needed
- Linked references or appendices on radiation calculations needed
- SAD did not have a Maximum Credible Incident section (e.g., max D gas event, max direct radiation exposure, etc.)
- Engineered and administrative controls for non-standard industrial hazards not included in safety envelope (e.g., SIS/HIS operability, ODH protection system operability, etc.)
- Safety envelope does not include engineered and administrative control supports such as calibration frequency, testing frequency, configuration management for shield drawings
- No documented practice to measure and track integrated neutron fluence in safety envelope
- Assurance processes beyond QA (e.g., ACC) not described in the SAD

Comments

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

- Safety of rf system not adequately analyzed in SAD

Items Requiring Resolution Before ISTP

- Finalize SAD/SE
    - Address all non-standard industrial hazards (NSIH) for all enclosures and the basis for inclusion in SAD
    - Include sections that describe the assurance processes such as ACC
    - Include methodology to determine NSIH controls, and link NSIH controls to safety envelope
    - Identify tangible controls in safety envelope and their supports
    - Supporting safety related calculations need to be linked or appended to SAD

Items Requiring Resolution After ISTP

- The web based work control system should automatically forward work related to limits and controls in the safety envelope to the ACC

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

ANSWER TO CHARGE 3

Charge 3: Are there clearly defined operating procedures that ensure that NSTX is commissioned and operating within the safe operating envelope as defined by the SAD and Safety Certificate (including off-normal events)?

- Conditional yes, subject to Items Requiring Resolution

Committee members for Charge 3

- Will Oren (TJNAF), Edward Lessard (BNL)

Method of review:

- Document review, interviews, observations, presentations

Findings

- Non-standard industrial hazards that are controlled by engineered safety systems or administrative safety programs (NSIH controls) are not clearly identified in the Safety Assessment Document, e.g. SIS
- There are no tangible NSIH controls or NSIH control supports in the Safety Certificate
- There is no implementing procedure that ties responsible positions to credited controls in a Safety Certificate (e.g. identify responsible authority for assuring SIS is tested and operational).
- The limits in the Safety Certificate are not related to tangible controls that must be present during operations (e.g. what is tangible control for the lithium limit?)
- 19 NBI procedures have been expanded to include preparation for and safe operations of beam line 2
- Administrative procedure OP-NSTX-02, which is managed by the COE, lists the sub-systems and integrated system procedures for startup and operation of NSTX-U
- ACC is an assurance process/program that addresses technical ESH issues, reviews projects and modifications against the requirements in the safety envelope and assumptions in the SAD, and it performs readiness review activities. However, implementing procedures beyond the charge were not documented (e.g., procedure to request a review, procedure that describes the ACC activities, tracking of ACC issues to closure, records of the reviews, authorizations to operate the facility or to modify safety systems identified in the Safety Certificate).
- No discussion of purge procedures in SAD regarding D gas event and NSIH controls such as mandatory purge gas volume

- Work packages and controlled documents are readily retrievable; but not completely error free
- Some procedures out of date
- Software QA process not defined

Comments

- Findings indicate inadequate QA/QC on procedures, which is needed to assure they are implemented as intended

Items Requiring Resolution Before ISTP

- Administrative controls, such as procedures, are needed to stay within limits in safety envelope and need to be included in the safety envelope (e. g., procedures associated with limiting the LITER lithium capacity, boronization, neutron limit logging, and shield configuration management)
- Engineered controls such as minimum purge gas volumes, operability of SIS, etc. must be in Safety Envelope

Items Requiring Resolution After ISTP

- QA procedures/programs to regularly audit the thoroughness of use of installation, checkout and operations procedures needs to be established
- Develop auditable procedures for ACC process/program/authorization as it relates directly to implementation at NSTX
- Develop associated training for ACC process/program as it relates directly to implementation at NSTX

ADDENDUM TO CHARGE 3

Although not specifically asked to comment on machine protection in either Charge 1 or 3, it was felt by the committee that the role of the Digital Coil Protection System in the machine protection was significant enough to be worthy of comment.

Findings

- The hardware of the Digital Coil Protection System has a comprehensive redundancy and fail-safe architecture.
- The physical architecture employed modern low-cost 16-core chips in a standard rapidly exchangeable plug-in format, so that an adequate spares stock could easily and usefully be achieved.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

Comments

- The system makes extensive use of a custom, made-to-order design of a multi-channel digitizer with multiplexed fiber-optic output, raising questions of design validation and lifetime, or Mean Time Between Failures. It would seem worthwhile to identify their failure modes in a simulation of their anticipated workload and working environment.

- In the longer term, the importance of the DCPS for machine protection surely warrants a comprehensive verification and validation process, not just for the early usage but evolving with the machine and the physics program and developing understanding of the potential threats to the tokamak assembly.

Items Requiring Resolution – URGENT

- To the extent that resources permit, develop a suitable testing plan, including a hardware simulator to challenge one or more examples of these digitizers, both inputs and outputs, over an extended period, in order to:
    - Prove longevity by burn-in (at least some hundreds of hours);
    - Identify repeated types of failure and redesign or acquire spares to suit the full set of such digitizers used in NSTX-U and its hot spares.

Items Requiring Resolution After ISTP

- Depending on the results of the simulator trials, acquire suitable spares and consider modifying the design to obviate any weaknesses identified.
- Continue monitoring the success or failure rate of the digitizers and adjust spares holdings, preventative maintenance planning, and design evolution accordingly.
    - Validation and verification of the coding within DCPS should be undertaken by suitable procedures such as by modeling (evolving with increasing physics understanding) and by cross-correlations with strain sensors, temperature sensors etc. on the load assembly.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

ANSWER TO CHARGE 2

Charge 2: Are there clearly defined roles, responsibilities and training for NSTX-U operations personnel?

- Conditional yes, subject to Items Requiring Resolution

Committee members for Charge 2

- Jim Irby (MIT Plasma Science and Fusion Center), Dave Terry (MIT PSFC), Will Oren (TJNAF), Edward Lessard (BNL)

Method of review:

- Document review and interviews. Interviews included COE, Operations supervisor, Responsible Line Management, Cognizant Engineer, System Operator, and Entry Level engineer

Findings

- There is an outstanding culture of safety. All employees felt safe at PPPL and all commented on their own about how impressed they were with the safety program

- The people we interviewed gave very similar answers to the questions indicating there was a very good training in roles and responsibilities

- We found that all but one of the employees interviewed have been at PPPL for many years (> 20), and have extensive experience in many areas. Some concerns were mentioned about the need to train new people and transfer information as long-term people leave. Our one new employee indicated to us that this process is underway. Others said they were working with other engineers to make sure knowledge is not lost.

- Training requirements are documented and approval process is in place. All employees knew about this process, and how to use the online training tools.

- The situation regarding multiple-role position holder succession seems not to be recognized by some of the position-holders interviewed, whose response to queries on this issue was to debate which of the other near-retirement, highly skilled staff could be further trained to successfully to take over the multi-role posts.

- Several people were concerned about out of date procedures or new incomplete procedures for NSTX-U, but they felt the system in place would make sure these procedures were ready before CD-4. One person was concerned about the DCPS. One person was concerned about the CHI system readiness because of loss of experienced personnel. Finally, someone mentioned there are too many acronyms (but improved with webpage update)

Report from NSTX-U Readiness Review Committee (continued)

- Process to determine what type of training for each procedure not defined in a procedure
- Roles, Responsibilities, Authorities and Accountabilities (R2A2) of COE not defined/represented in operating org chart
- The structure with roles and responsibilities of each position beneath the COE was not presented
- Conduct of Operations Order Matrix not developed

omments

- Shift supervisor and COE roles could be better defined and made more clear in the documentation
- What role does the physics operator play in machine operation? How do physics operator and COE interact to ensure safe operation of the machine? The roles should be better defined.
- Suggest more training for COGs and COEs in ACC process and SAD and safety envelope
- It would serve the lab better, against the various reasons for loss of staff, if there was one person (and a deputy) per key role. While there is currently no evidence of the multiple roles carried by any one person leading to any conflict of interest (such as science program expediency versus the priority of definite safe working) we do not feel that this is a good policy.
- Above findings indicate R2A2s not well documented for operations organization
- Other attributes of the Conduct of Operation Order may not be documented or clearly implemented.
- Continued attention should be paid to succession planning since many of the staff are approaching retirement age. This is especially important in light of the fact that some of the staff performs multiple roles.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

ANSWER TO CHARGE 4 and 5

Charge 4: Does the PPPL Activity Certification Committee (ACC) process ensure that configuration changes are adequately reviewed and appropriately documented in the NSTX-U Safety Assessment Document (SAD) and Safety Certificate?

Charge 5: Does the PPPL Activity Certification Committee (ACC) process, including approval to proceed by the PPPL ES&H Executive Board Chairperson, ensure that PPPL is indeed ready to begin NSTX-U operations?

- Yes, subject to items requiring resolution.

Committee members for Charges 4 and 5

- Kevin Freudenberg (ORNL), Dragoslav Ciric (CCFE), and Tim Scoville (GA)

Method of review:

- Document review and interviews.

Findings

- The existing ACC review process is functioning as an internal readiness review, but in places there is no evidence of external input, to the extent that some serious issues have been missed.
- The experience of the ACC members, and their "hands-on" approach to checking the plant has been and continues to be of immense value for the human safety and plant protection of the facility.
- The guideline for determination of the scope of the ACC review is based primarily on the OP-NSTX-02. However, the ACC review has full authority to expand its scope into any area it sees fit.
- The NSTX-U safety certificate is issued by the ES&H Executive Board based on the recommendation of the ACC review. The safety certificate is required for NSTX-U operation.
- Maintenance activities are not directly input into NSTX-02 or the ACC review process.
- Spot checks of the commissioning procedures and the FMEA, reveal some shortcomings most easily explained as arising from the familiarity of practically every key post-holder with the old plant and its hazards.
  - The typical problems are, in the commissioning procedures, inadequate descriptions of how exactly to perform certain tasks (such as "check the type of gas in the [SF6 towers]", and inadequate requirements for recording findings or branch conditions if certain conditions were not met (e.g. vacuum pressure achieved).

- For the FMEA the old plant and the new differ more than the NSTX-U FMEA recognized (although it is unclear to what extent ACC had approved this document at the time of this Review). One example is that the turbo-pumps will see higher stray magnetic field from the tokamak poloidal fields, which will create higher eddy current heating in the rotor blades, exacerbating their creep behavior and raising the likelihood of explosive disassembly – a serious failure mode of TMPs guarded against by modern suppliers and by many other MFE installations but not mentioned as a hazard in the FMEA.

Comments

- The ACC review was stated to be on time and within schedule but this was not shown explicitly. There is concern that many systems, most notably the DCPS, need to be fully approved and ACC assessment is only half done on that system.
- Responsible line manager decides (engineering judgment) when modifications are big enough to make change to SAD.
- The schedule for bringing NSTX-U up was not discussed in any detail. The ACC stated that their involvement was "just in time" and driven by the new systems coming up that needed review.
- The ACC effectiveness relies heavily on their considerable years of experience to guide activities. However, as senior staff retires, an improved process become more important.
- Since ACC members are themselves part of the long-term cognoscenti of the facility, it is not clear that their further efforts alone will identify the new hazards raised by the change from NSTX to NSTX-U or the unstated things in the commissioning procedures that are not obvious to trainees and other new-comers.
- It would be beneficial to create and maintain a preventative maintenance database.

Items Requiring Resolution Before ISTP

- The NSTX-U Operations group should provide a well-defined startup schedule for use by the ACC and other groups. Hold points should be used to trigger the involvement of the ACC in approvals.
- Consider how to identify the unstated reliance upon prior knowledge in the commissioning procedures. Improvements should be made such as recording values observed (useful for maintenance guidance and confirmation of tasks actually completed).
- Preventative maintenance (PM) activities should be input into NSTX-02 or the ACC review process when applicable, since PM activities may impact assumptions in safety analysis. Explicit decisions should be required by Cog and approved by RLM on whether completeness of maintenance activities is appropriate for startup.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

- Arrange for external peer review of the FMEA and evaluate whether any new issues identified must be resolved prior to ISTP.

- **Issues Requiring Resolution After ISTP** Any changes to the NSTX-02 that impacts a control identified in the Safety Certificate or an assumption in the SAD document must automatically trigger an ACC review. This should be included in the PPPL tracking/change system to remove the ambiguity of when an ACC review is required.
- A skill profile for future ACC members is needed.
- At a suitable interval, reassess the ease of use of the procedures by new trainees.

Appendix M

Report from NSTX-U Readiness Review Committee (continued)

ANSWER TO CHARGE 6

Charge 6: At the time of project completion, will the NSTX Upgrade Project have delivered the Project Objectives as defined in Section 2.2 of the NSTX-U Project Execution Plan?

Yes. It is the opinion of this committee that the demonstration of the two items listed above (Section 2.2.2.2 in the NSTX Project Execution Plan (PEP)), coupled with the successful completion of the required action items, and the completion of the integrated testing OP-NSTX-U will demonstrate that NSTX has been upgraded to permit operation at the desired technical baseline parameters. This will meet the project objective, as defined in Section 2.2.1 of the PEP.

Method of review:

- Document review and presentations during the Readiness Review.

Findings

- The Technical Baseline Parameters for the NSTX Upgrade Project are the following: TF = 1.0 Tesla, Pulse length = 5 seconds, Plasma current = 2 MA, and NB Power = 10-14 MW
- The Center Stack Upgrade and the additional of the second Neutral Beamline will provide the device capabilities to meet the baseline parameters.
- All systems have been designed to meet the baseline parameters. Design reviews have been held for all key systems and have been reviewed by internal project personnel as well as external reviews through the final design review stage. All action items (Chits) identified during the reviews were listed and tracked in a master action item file.
- A procedure exists and is being executed to verify that all action items are resolved, that appropriate personnel have reviewed the resolutions, and that the resolutions are completed prior to the start of integrated testing OP-NSTX-02.
- The execution of the design was reviewed periodically during the project by external review committees and all recommendations of those committees were followed.
- Formal project completion requires demonstration of (1) an ohmic plasma with Ip > 50 kA at a toroidal field greater than 1 kG and (2) installation of the second neutral beamline, including all support services and control systems, and injection of a 40 keV neutral beam into vessel armor for 0.050 seconds.

Comments

- Actual achievement of the baseline parameters over the course of the next few years will require continued testing, including validation of design simulations against measurements.

Appendix N

NSTXU Safety Certificate

PPPL PRINCETON PLASMA PHYSICS LABORATORY

SAFETY CERTIFICATE

LOCATION (Site, Area, Bldg., Room, etc.)
D-Site Bldgs and C-Site NSTX Control Room

ACTIVITY (Brief Description)
Operate NSTX-Upgrade (NSTX-U)

LIMITATIONS:

1. Maximum neutron generation rate from plasma operations is 4×10^{18} DD neutrons/year per the running total required by OP-NSTX-015, "NSTX-U HPP Daily Operations."
2. Operation of the Bakeout Systems may be performed to heat the plasma facing components (PFCs) to temperatures up to 350°C and the torus vacuum vessel to temperatures up to 150°C per OP-G-156, "NSTX Integrated Machine Bake-out Operations."
3. Boronization with deuterated Trimethylboron (dTMB) may be performed with no more than 50 grams of TMB at risk in the NSTX-U Test Cell at any time per OP-G-155, "NSTX Boronization using TMB."
4. The total maximum active elemental lithium inventory in the NSTX-U Test Cell during an experimental campaign will not exceed 2,000g per OP-VAC-762, "NSTX LITER Operating Procedure."
5. No access into the NSTX Test Cell is permitted during plasma operations or when the NSTX-U toroidal or poloidal magnetic field coils are energized by high-power supplies. Complete OP-NSTX-014, "NSTX Machine Operation Guide for Startup and Shutdown" each run day.

CONDITIONS FOR OPERATIONS:

1. Controls are implemented per Chapter 5 of the NSTX-U Safety Assessment Document (SAD).
2. COEs are trained in the requirements of the NSTX-U Safety Assessment Document (SAD) per OP-NSTX-012, "NSTX-U Operations Training."
3. The criteria of procedure OP-NSTX-02, "Startup of NSTX-U" must be satisfied.
4. The machine operating parameters will be bound by the most recent completion of ISTP-NSTX-001, "NSTX Coil Energization Tests".

RESPONSIBLE LINE MANAGER:

Alfred von Halle	[signature]	4/10/2015
Print Name	Signature	Date

APPROVED BY (ES&H/EB Chairperson):

Adam Cohen	[signature]	4-10-15
Print Name	Signature	Date

ACTIVITY COMPLETED (Dated and Signed by Responsible Line Manager)

Print Name	Signature	Date

Appendix O

NSTX OH Fault Corrective Action Plan

NSTX OH Fault Corrective Action Plan

Rev. 1

Reviewed by: ______________________
M. Ono

Reviewed by: ______________________ Digitally signed by Jonathan Menard Date: 2015.08.01 13:37:19 -04'00'
J. Menard

Reviewed by: Ronald L. Strykowsky — Digitally signed by Ronald L. Strykowsky DN: cn=Ronald L. Strykowsky, o=Princeton Plasma Physics Laboratory, ou=PPPL, email=rstrykow@pppl.gov, c=US Date: 2015.08.02 13:13:19 -04'00'
R. Strykowsky

Reviewed by: Alfred von Halle — Digitally signed by Alfred von Halle DN: cn=Alfred von Halle, o, ou, email=avonhalle@pppl.gov, c=US Date: 2015.08.03 06:33:05 -05'00'
M. Williams

Reviewed by: Adam Cohen — Digitally signed by Adam Cohen DN: cn=Adam Cohen, o=Princeton University, ou=PPPL, email=acohen@pppl.gov, c=US Date: 2015.08.02 21:51:44 -04'00'
A. Cohen

Approved by: Stewart Prager — Digitally signed by Stewart Prager DN: cn=Stewart Prager, o=Princeton Plasma Physics Laboratory, ou=Director, email=sprager@pppl.gov, c=US Date: 2015.08.02 22:04:41 -04'00'
S. Prager

Appendix O

NSTX OH Fault Corrective Action Plan (continued)

Background:

On April 24, PPPL ESU responded to alarms from the NSTX-U experimental area. An active water leak from NSTX-U was observed. Staff discovered that several of the Ohmic Heating coils external cooling paths were damaged at the top end of the OH coil. Additionally, indications of electrical arcing were observed in the vicinity of the water leaks. Initial inspection showed no damage to the OH or other coil systems. The water was secured and investigation into the cause was initiated.

Review Teams:

As a result of this event, the Laboratory has commissioned a number of reviews to evaluate the cause, determine what actions are necessary to repair the coil, what actions are necessary to improve processes and prevent recurrence. The following teams were commissioned:

- An Internal Independent Review team, comprised of: Robert Ellis, Chair, Michael Bell, John DeLooper, Joel Hosea, and Charlie Neumeyer conducted a formal review on May 8. Their report, issued on May 12, identified 32 recommendations. The recommendations for this report are label as no's 1 (IRR) through 32 (IRR).

- The PPPL Advisory Board meet on May 13 and 14 and were given a summary of the event. Their report, issued May 15, identified 3 recommendations. The recommendations for this report are labeled as no's 33 (PAC) through 35 (PAC).

- An Extent of Condition Review Team, comprised of: J. Hosea, chair, R. Ellis, N. Greenough, D. Mueller, issued their report on May 26, with 25 recommendations. The recommendations for this report are labeled as no's 36 (EOC) through 60 (EOC).

- An Independent External Review Team, comprised of: Arnie Kellman, chair, General Atomics; Jim Irby, MIT Plasma Fusion Center; Brad Merrill, Idaho National Laboratory; and George Ganetis, Brookhaven National Laboratory issued their report on May 28, with 14 recommendations. The recommendations for this report are labeled as no's 61 (IER) through 75 (IER). Note that item 75 was in error and is not associated with any recommendation.

- A formal Root Cause Analysis Team, comprised of Irving Zatz, John Lacenere, Judy Malsbury and Mike Mardenfeld was commissioned. This report identified some 20 Judgements of Need (JONs). These JONs are label as no's 76 (JON) through 95 (JON)

Corrective Actions:

Since many of the recommendations were related, this corrective action plan groups the recommendations into major areas for action and tracks the items by these groupings.

This plan also specifies which actions need to be done before CD-4 and which can be accomplished after CD-4. Category A corrections must be done before CD-4 while Category B actions can be actions can be accomplished subsequently.

Revision 0	Original Issue
Revision 1	Added Judgements of Needs (JONs) from Root Cause Analysis Report and updated status column as of July 30, 2015

Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
1	A	1 (IIR)	Determine the root cause of the ground plane connector design/installation errors [Separate committee using procedure QA-019]	1-1 Form a team to Conduct a Root Cause Analysis per QA-019 before CD-4 1-2 Complete Root Cause Analysis report 1-3 Incorporate recommendations (Judgments of Need) into this CAP	Zatz	OPEN (Root Cause Rpt, rev 0 issued; rev 1 of this CAP will allow closure)
		20 (IIR)	Complete root cause analysis and be prepared to present to external committee			
		64 (IER)	A Root Cause Analysis must be delivered to the ACC prior to approval of restart of high power test operations.			
		34 (PAC)	Ensure that PPPL identifies and addresses the correct fundamental root causes and complete extent of conditions for the external review committee to validate			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
1A	B	1 (IIR)	Determine the root cause of the ground plane connector design/installation errors [Separate committee using procedure QA-019]	Issue Revision 1 of Root Cause report with attachments. Review for any further updates of this CAP	Zatz/ Williams	OPEN

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
2	A	15 (IIR)	The project needs to develop a comprehensive plan to address the Extent of Condition charge question and be ready to present to the external review committee	Extent of Condition committee was formed. Their report was issued May 26. The recommendations from that report have been incorporated into this corrective action plan.	Hosea	Closed – 5/26/15
		16 (IIR)	Form a small "task force" (with appropriate expertise) to walk down all the high-voltage parts of NSTX-U to determine anything out of the ordinary, or potentially questionable from an "high voltage hygiene" stand-point			
		17 (IIR)	Evaluate other gaps, creepage paths, and insulation on other coils and appendages to see if problems exist similar to OH			
		33 (PAC)	Evaluate PPPL conduct of engineering and conduct of operations policies and the execution of those policies, roles and responsibilities, accountability and authority, and organization, as part of the extent-of-conditions task force review. Include interviews with engineering and NSTX operations staff			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
3	A	2 (IIR)	Continue to perform diagnostic electrical tests including repeat of coil resistance measurement, inductance measurement and impulse test to confirm that the turn-to-turn insulation is intact	Conduct tests per PTPs and ISTP for restart. Engineering will determine which portions of the PTP's and ISTP need to be rerun once the machine is reassembled.	von Halle	OPEN #2 closed #68 closed #73 closed
		65 (IER)	An Impulse test should be done to fully qualify the OH coil			
		68 (IER)	The inner and outer vessel Hi-Pots must be successfully completed before returning to CD-4			
		73 (IER)	Careful attention must be paid to the recommissioning of the machine after the recovery effort. It may be best to err on rechecking more systems than less since some things may have been inadvertently affected during disassembly.			

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Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
4	B	18 (IIR)	Analyze and document electrical effect of Aquapour and dental floss wires in gap between OH and TF	Calculations complete being reviewed. No changes anticipated	Titus	Closed - 7/7/15
		56 (EOC)	Aquapour/Epoxy between TF inner bundle and OH Center Stack - Operation of OH and TF combined with PLC controlled water heater to program the water temperature profile; Controlled through DCPS using I^2t; Constrains the pulse repetition rate.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
5	A	6 (IIR)	Determine NSTX-U project line of authority - who must approve proceeding with operations if causes of ground fault (or other problem causing a trip) have not been determined and resolved	Project will determine appropriate lines of authority, roles and operational methodology for off normal events and then define in an administrative procedure new administrative procedure will be put in force to define the expected responses for each of the full set of protection systems..This will include directions to get approvals from the appropriate subject matter experts from engineering, research, and management. Key control room personnel will be trained on the requirements of this procedure. The procedure for the D---Site Control of System Status (Chain of Command), OP---AD---56, will be revised and approved	Ono/Menard/von Halle/Williams	OPEN #4 – Closed #6 – Closed #8 – Closed #10 – Closed #35 – Closed #60 – Closed #61 – Closed
		8 (IIR)	The Laboratory should determine whether the operators (e.g. COEs) report up to and through the NSTX-U organization rather than engineering			
		10 (IIR)	Project needs to demonstrate how it will prevent this type of management control failure from recurring in the future			
		60 (EOC)	Chain of command during operations. –Clear line of command to and from the COE during off-normal events			
		4 (IIR)	Revise operational procedures to require a full stop of operations upon a ground fault trip – need to understand what went wrong – require inspections to determine reason			
		61 (IER)	The procedure for handling off-normal events including ground faults must be completed prior to restart of testing. This must address the control room conduct of operations including required personnel, the amount of discretion that operations personnel have in continuing a given test campaign, i.e. when can protection systems be bypassed. Operations must stop until a serious fault condition is understood before proceeding.			
		35 (PAC)	Reinforce workforce authority to stop work, especially when anomalies are observed			
		93 (JON 19)	The Chain of Command for Control of Equipment and System Status, defined in OP-AD-56, failed to prevent the event and needs to be reviewed and corrected.			

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Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
6	A	5 (IIR)	COEs should have a collection of MDS Scope pages set up to monitor critical operations and diagnose faults under operations procedure. The pages used should be optimized for the type of operation underway (test shot, ISTP, plasma ops, etc.)	6-1 Develop and implement scope pages for PS EICs and COEs. Some optimization of critical info necessary to avoid overload 6-2 The available MDS scope pages will be evaluated and documented for use by key control room personnel. 6-3 Control Room personnel will be trained on their use. 6-4 Adequacy of COE station computers and displays will be reviewed with the COE's, and appropriate updates made.	von Halle	OPEN
		67 (IER)	The signals from all ground fault signals should be digitized and made easily displayable by the operations group.			
		58 (EOC)	Adequacy of control room computers and associated displays for the COE.			
		72 (IER)	Improvement in instrumentation to aid in identification of causes of off-normal events should be addressed. This is true not only for ground faults, but any signals that provide interlocks for serious machine shutdown conditions.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
7	B	14 (IIR)	Engineering needs to establish rules for grounding each experimental machine as part of the formal design review process	7-1 A formal grounding policy will be developed and deployed as well as a SME for grounding will be appointed 7-2 The PPPL System Engineer list will be reviewed and updated to include an equipment grounding Subject Matter Expert who will provide engineering input in establishing this policy	von Halle	OPEN
		63 (IER)	A policy for equipment grounding must be developed			

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Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
8	A	3 (IIR)	The design of the OH ground plane and its connections needs to undergo the standard PPPL design review, installation and inspection process, rather than relying on a "field fit-up."	8-1 Assure that all design changes undergo as a minimum, a final design review, per ENG-032 8-2 Assure that all appropriate design documentation is placed in the Operations Center	Dudek	OPEN #3 – Closed #11 – Closed #13 – Closed #70 – Closed #74 – Closed
		11 (IIR)	Project needs to verify design documentation packages (CDR, PDR, FDR) are available in the operations center for the NSTX-U centerstack and beamline 2			
		13 (IIR)	Incorporate electrical analysis and design into development of upgraded components			
		62 (IER)	A systematic check of all installation packages for NSTX-U must be performed with the object of identifying any other field installations and then evaluating whether they were installed properly. This review team should include at least the cognizant engineer and installation technician.			
		70 (IER)	Complete implementation of design changes identified by the team			
		74 (IER)	Assuming design reviews are properly completed, as per normal PPPL procedure, and installation process is carefully reviewed and inspected, the committee believes that the reassembly of the machine can proceed			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
9	B	32 (IIR)	Consider installing real-time camera(s) and arc flash detectors inside hub assemblies	Will evaluate and determine feasibility – incorporate post CD4	Dudek	OPEN October 15, 2015.
		59 (EOC)	Add cameras for real-time viewing of critical machine components			

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Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
12	A	26 (IIR)	For new design of clamps that support OH water lines: ensure adequate gaps, creepage, and insulation to pass hipot at 1.5 x Voh_hipot; use insulating boot over water line as it emerges from coil; do not use metallic screws; avoid splits in G10 blocks that provide line of sight creepage path	New design has been developed with input from electrical engineers. Design subjected to final design review and then issued to field for construction	Raftopoulos	CLOSED
		29 (IIR)	Evaluate whether or not method for clamping of OH water fittings allows for radial expansion of coil copper while support structure remains fixed, without placing undue stress on the water fittings. Consider placing a bend in the water fitting to avoid this issue			
		41 (EOC)	OH Water Connections: •Need an approved design with proper insulation - underway – Original parts were field fit. –New design must have electrical engineering input to insure proper high voltage insulating techniques - underway.			
		71 (IER)	Properly insulated the water cooling tubes while maintaining the ability to detect water leaks			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
13	B	23 (IIR)	Consider scheme to monitor load impedance in PSRTC (and/or DCPS) to sense situations where coil has become degraded	Code revised, tested and implemented	Gerhart	CLOSED

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
14	B	7 (IIR)	Engineering needs to establish a policy for field installations – when does a review have to be completed of field design	Develop field installation policy; Revise WP procedures accordingly. Issue statement of field change policy per PMO procedures to COGs and RLMs. Include in next COG/RLM training. Due 8/1/15	Perry/Stevenson	CLOSED

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Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
15	B	54 (EOC)	Bakeout Constraints on Machine Operations: Failure to reach desired 350C bakeout for divertor tiles is predicted. Refer to PF-1A, B, and C considerations; High temperature is needed for bakeout of divertor plates to provide for good plasma performance. Preparations need to be made to add hot He gas heating to the divertor plates to reach desired temperature of 350C. Discoloration of CHI leads after Center Stack bake. Need to understand the cause	15-1 The urgent task is to install bakeout compatible tubes which are accessible from outside the umbrella structure compatible to be installed for the vertical and horizontal divertor sections. This task will be completed prior to CD-4. 15-2 Through realistic thermal modeling and on-going material temperature testing, a bakeout heating scheme will be chosen if any before the bakeout. 15-3 Risk- benefit assessment for PF-1B will be performed in deciding the heating system if any before the bakeout. 15-4 The cause of the CHI leads discoloration will be determined prior to the next bakeout 15-5 With the thermo-couple placed on PF-1C, we agree that the excessive heating of PF-1C can be avoided administratively. A clear set of operating constraints will be developed by the start of research operations	Ono/Titus	OPEN
		55 (EOC)	Bakeout Constraints on Machine Operations: Discoloration of CHI leads after Center Stack bake. –Need to understand the cause			
		53 (EOC)	PF1A, 1B, 1C Considerations: Bakeout issue with PF-1B (Art Brooks analysis). Divertor tiles will not reach adequate temperature unless heated by the He system. If heated by He, the G10 spacer and ground wrap of PF-1B will exceed allowable limits. There is also the issue of stress in the welds securing PF-1B upper and PF-1A upper. Management must decide whether to bake to over 300C and accept risks to PF-1B. Connections to divertor plates must be able to accommodate the He heating system.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
16	B	51 (EOC)	PF1A, 1B, 1C Considerations•Shorting between PF-1A ground wrap and OH ground plane. It cannot be repaired without removing center stack. What are the ramifications? Minor.	Since PF-1A ground warp and OH ground plane are grounded to the same potential, we do not see any ramifications. With the thermo-couple placed on PF-1C, we agree that the excessive heating of PF-1C can be avoided administratively. A clear set of operating constraints will be developed by the start of research operations	Ono/Titus	OPEN
		52 (EOC)	PF1A, 1B, 1C Considerations: PF-1C can be heated by the plasma: Only a minor issue when PF-1B is not energized, but the strike point can still hit the PF-1C can; Energizing PF-1C so as to push the strike point towards the plasma will avoid this; Operations can administratively avoid the problem; A clear set of operating constraints needs to be developed.			

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NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
17	B	9 (IIR)	The Laboratory needs to determine whether sufficient high voltage electrical expertise is available for current and future projects	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN
		82 (JON 7)	PPPL needs to capture the institutional knowledge held by experienced staff and current best practices by creating formal internal technical standards and ensure that they are readily available and applied uniformly.			
		83 (JON 8)	PPPL needs to capture institutional knowledge held by experienced staff by expanding formal training systems for positions requiring critical technical skills that are specific to PPPL.	Succession Plan – Von Halle effort to capture by posting of positions (addresses part of JON 7 and 8)		
		84 (JON 9)	PPPL needs to evaluate the current skill mix among staff and develop a detailed succession plan.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
18	B	12 (IIR)	OH coil hipot level should be 2E+1=2(6+2)+1=17kV per approved design point documentation, which was also checked and signed off by coil designer. If operation requirements are to be revised (e.g. OH <=4kV with CHI, and/or Vchi = 3kV) then relevant documentation should be revised accordingly	Review hi-pot requirements and document accordingly. GRD will be revised to ensure consistency with PTP's.	von Halle	OPEN

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
19	B	19 (IIR)	Consider conducting a "blind spot" review, similar to the laboratory process	Similar approach for Laboratory operations will be evaluated on the NSTXU facility by 10/31/15	Williams	OPEN

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NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
20	A	21 (IIR)	Ensure that ground plane connection does not form toroidal loop. If hose clamp approach is used to attach ground plane connector, ensure that type with thermal expansion spring is used. Demonstrate through measurement that the desired resistance is in the loop	Overall grounding plan will be incorporated in the final design. Required measurements will be taken via procedures and documented. Testing of grounds will become part of the operational procedures The PPPL System Engineer list will be reviewed and updated to include an equipment grounding Subject Matter Expert. This engineer or designee will review, approve and inspect equipment grounds All coil system power feeding into the umbrella structures should have ground fault sensors to measure any ground leakage current. Ground fault relaying should be provided with ground current sensor measurements and annunciation available in the Control Room	Raftopoulos/ Dudek	CLOSED
		22 (IIR)	Consider conducting elastomer solution to ground plane electrical attachment to avoid use of flex copper braid (ref. 13_010220_CLN_01.pdf, 13_010222_CLN_01.pdf, 13_010301_CLN_01.pdf). Provide documentation and drawings to justify and describe solution			
		25 (IIR)	Measure resistance of ground plane paint to confirm proper application and resistivity (200 ohms/square). Determine if OH groundwall thickness and composition is different than given in design point (as was mentioned during presentation) and provide explanation			
		28 (IIR)	Connect all metallic structures of inner vacuum vessel to Cat. 3 ground with 10 ohm resistors in each connection that can be opened up for troubleshooting. Provide an approved drawing of the electrical schematic			
		30 (IIR)	OH ground plane should be connected to Cat. 3 ground reference on both top and bottom ends through 10 ohm resistors. Analysis of ground plane behavior using PSCAD (W. Que "OHCoilGroundPlaneV3.ppt") should be updated accordingly and properly documented			
		36 (EOC)	OH ground plane and connection overall design: Do we need a lower ground plane connector? Evaluation is required. Design, fabrication, installation, connection and inspection of ground plane connector(s). Ground through a 10 Ohm resistor			
		31 (IIR)	Ensure that OH preload assembly fixture is connected to Cat. 3 ground via 10 ohm resistor			
		37 (EOC)	OH Compression Stack Grounding –Through a 10 Ohm resistor.			
		38 (EOC)	Grounding of buss supports at bottom of machine			
		39 (EOC)	Grounding of metal spacers to TF water connector supports			
		40 (EOC)	Who has an overall understanding of the machine grounding? Who is in charge of grounding, inspection thereof, and documentation on NSTX-U? The latter individual should have the qualifications of the former.			
		66 (IER)	Additional ground fault sensors should be added to the new OH ground straps, and the signals made part of a quickly acting ground fault relay. The OH preload stack should be grounded properly and sensors added and their signals recorded			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
21	B	27 (IIR)	Consider placing water sensor(s) on floor of NSTX-U Test Cell under machine and interlock with water system to turn off pumps	Will conduct a review to determine benefits and consequences by 10/31/15	Dudek	OPEN

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NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
22	A	57 (EOC)	Ground fault/loop detector sensitivity lessened by capacitors installed across HHFW transmission line DC breaks. Used in the past with the same capacitors. Loop faults are present in the diagnostic ground system.	Ground fault/loop detector sensitivity reduction due to capacitors installed across the HHFW transmission DC breaks has been measured, and the capacitors may now be reinstalled. Known loop faults in the diagnostic ground system need to be evaluated and dispositioned.	von Halle	CLOSED

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
23	A	69 (IER)	Install Lexan sheets or a similar insulator at the bottom of the machine to make sure that metal objects are not drawn up by the magnetic field into the bus work and connections	Peer review to determine requirement by June 12, 2015	Perry	CLOSED

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
24	B	73 (IER)	Although not unique to PPPL and NSTX, we believe that the lab and the fusion community as a whole could benefit from community workshops on best practices in engineering and operations. Discussions concerning measurements of joint resistance (periodic and real-time), ground fault detection highlighted areas in which techniques exist in different fusion and/or DOE labs that would benefit the larger community. While not truly a systemic weakness, such an initiative could strengthen NSTX-U and other device operations and safety.	Reinstitute Fusion Facilities Operations Committee by 10/1/15.	Williams	OPEN

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
25	B	75 (IER)	DELETED – NO SPECIFIC RECOMMENDATION WITH THIS ITEM.	N/A	NA	N/A

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NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
26	B	76 (JON 1)	PPPL needs to ensure that a comprehensive Technical Risk Assessment and Management Strategy provides direction for balancing resource allocation with technical assurance. This strategy needs to be appropriately graded for all levels of work.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN
		85 (JON 10)	PPPL management needs to evaluate if the Laboratory's Organizational Structure inadvertently encourages some of the issues highlighted in the Contributory Causes including staff accountability, staff assignments and competency, information access and communications.			
		86 (JON 11)	PPPL needs to clarify the roles and responsibilities of the Cognizant Engineer, the ATI, and the System Engineer as mentioned in the Work Planning System and Procedures. PPPL needs to ensure that they are being implemented properly, without overlapping or missing coverage.			
		95 (JON 20)	Protections need to be built into PPPL systems to prevent human performance issues from having a negative impact: Clear Goals, Roles, and Responsibilities; Appropriate Checks and Balances; Distinct Problem Solving Skills; Validation of Assumptions; Unfamiliarity with tasks; Recognizing Degraded Proficiency; Technical Stop Work; Inadequate communication.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
27	B	78 (JON 3)	PPPL needs to adopt and implement best practices from "Systems Engineering", especially for large complex projects which are composed of many subsystems.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN
		87 (JON 12)	PPPL needs a rigorous process to ensure that each component or system is assigned to a clearly identified individual who is aware of its current and ongoing status and history, and is someone who is both capable and responsible for its technical aspects.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
28	B	77 (JON 2)	PPPL needs to ensure that Lab---wide Procedures are clearly understood, used as a primary resource for directing work, and that they are properly implemented.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN
		79 (JON 4)	PPPL needs to ensure that the Work Planning System is utilized properly and consistently.			

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Appendix O

NSTX OH Fault Corrective Action Plan (continued)

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
29	B	80 (JON 5)	PPPL needs to continue to improve existing Project Planning and Control Tools.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN
		88 (JON 13)	The PPPL Design Review Process needs to be comprehensive, cover all important aspects or components of a work activity, and include all technical disciplines involved in the work activity.			
		89 (JON 14)	During the design phase and after the FDR, the project needs to ensure that the review process extends to as-‐built configurations including field changes.			
		90 (JON 15)	The Laboratory needs to assure that project specific technical procedures and drawings are appropriately and adequately reviewed.			

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
30	B	81 (JON 6)	PPPL needs to implement an information system (e.g. database) that relates all technical information to allow archiving and access.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
31	B	91 (JON 16)	An expansion of independent field oversight needs to be implemented.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN

CAP No.	Cat.	Recom. No.	Issue	Actions	Assigned to:	Status (as of 7/31/15)
32	B	92 (JON 17)	PPPL needs to review and clarify policies for Configuration Control of Experimental Devices to ensure that they are properly implemented with traceability and create adequate documentation of the device.	TBD – need meeting to establish long term corrective action – Cohen to call meeting by 9/15/15	Cohen	OPEN
		93 (JON 18)	Temporary configuration changes need to be formally documented and approved.			

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END OF REPORT